JC Branner
apl 8, 1917

MARYLAND GEOLOGICAL SURVEY
WM. BULLOCK CLARK, STATE GEOLOGIST.

THE APPALACHIAN REGION

PALEOZOIC APPALACHIA

OR

THE HISTORY OF MARYLAND DURING PALEOZOIC TIME

BY

BAILEY WILLIS

Special Publication, Volume IV, Part I.

THE JOHNS HOPKINS PRESS
BALTIMORE
November, 1900.

St

The Lord Baltimore Press
ΙΩΤΑ ΕΝ ΟΥ ΜΗ ΠΑΡΕΛΘΗ
The Friedenwald Company
BALTIMORE, MD., U. S. A.

CONTENTS

CONTENTS

MARYLAND GEOLOGICAL SURVEY
WM. BULLOCK CLARK, State Geologist.

The Appalachian Region

Paleozoic Appalachia

OR

The History of Maryland during Paleozoic Time

BY

BAILEY WILLIS

Special Publication, Volume IV, Part I.

THE JOHNS HOPKINS PRESS
Baltimore
November, 1900

PART I

THE APPALACHIAN REGION

PALEOZOIC APPALACHIA

OR

THE HISTORY OF MARYLAND DURING PALEOZOIC TIME

BY

BAILEY WILLIS

PART I

THE APPALACHIAN REGION

PALEOZOIC APPALACHIA

OR

THE HISTORY OF MARYLAND DURING PALEOZOIC TIME

BY

BAILEY WILLIS

THE HELIOTYPE PRINTING CO BOSTON

THE CITY OF CUMBERLAND AND "THE NARROWS" OF WILL'S MOUNTAIN.

PALEOZOIC APPALACHIA OR THE HISTORY OF MARYLAND DURING PALEOZOIC TIME

BY

BAILEY WILLIS

INTRODUCTION.

Some rocks consist of materials gathered beneath the sea and are marked by the water whose currents form them. They are laid in even beds; the surfaces of the beds are often rippled; they receive impressions of seaweeds and trails of crawling creatures; and marine animals become imbedded and are preserved in them.

The materials of which such rocks are formed are chiefly sand and mud (or mechanical sediment) and lime, which occurs in the sea in solution and may be precipitated by organic or chemical means. Rivers carry these substances down in great quantities and waves breaking along the shore sweep back the pebbles, sand, and stirred-up mud. When deposited beneath the water and consolidated, the tribute from the land delivered to the sea by streams and waves becomes conglomerate (pebble-rock), or sandstone (sand-rock), or shale (mud-rock), or limestone (lime-rock); and these varieties of sedimentary rocks occur in strata, the several kinds alternating and often grading one into another.

In Maryland all the rocks west of the Blue Ridge are sedimentary rocks, as is proved by their bedding, the marks upon their surfaces, and the fossils they contain; and it is known by studies of them that a sea extended where now are the mountains and valleys of this and adjoining states. That sea was not the Atlantic Ocean. It was an interior, or mediterranean sea which spread its sediments from Alabama to Canada and from central Maryland far west across the

Mississippi Valley. At least it grew to be so extended, although it was not so wide in the earliest time of which we have knowledge. The lands which bounded it lay to the east (in part where the Atlantic now rolls), to the southeast, and to the southwest. There were also lands on the west and north, but the sea was not completely shut in. There were probably several outlets from it to the ocean.

The interior sea widened in its earlier development and later narrowed. Its shore, the line between the sea and the land, migrated far across the land as the sea was extended, and returned across the sea-bottom as the waters shrank. That migration was not unhesitating; it paused, and retreated, and advanced again and again. When the sea expanded sediments were more widely spread; when the sea retreated, old rivers stretched after it, new streams developed on the freshly bared land, and new mountain chains grew up. The geographic changes of land and sea influenced climate, modified the kind of sediment sent to the sea, changed the conditions of its distribution over the sea-bottom, and caused variations of living types. The effects may now be observed in the sedimentary rocks which formed under successively different conditions, and from these effects the nature of the changes may be inferred with more or less probability of correctness according to the distinctness of the record and the simplicity of the conditions. In order to comprehend the significance of the strata and their varied sequences, it is necessary to understand the operations and relations of three great geologic processes, which affect the extent of continents and give rise to mountains. They are the processes of erosion, sedimentation, and deformation. Fully to discuss them would require a treatise on geology, but their natures may be suggested by illustrations drawn from their present operations; operations which repeat the conditions and events of the past.

GEOLOGIC PROCESSES.

Illustrations of Erosion.

Erosion is that process by which elevations of the land are worn down toward sea-level. It is carried out by the forces of the sun

acting through the atmosphere and the sea upon the land, and by gravitation. The process may be illustrated by describing the development of a coast and the work of rivers.

DEVELOPMENT OF A COAST.

In migrating backwards or forwards a coast assumes new features according to the form of the land across which it sweeps. At the meeting of the land and sea a level line is drawn across a plain, around a hill, or along the slopes of a valley; all below that line is submerged and the line becomes the shore.

Shores are of many types. There is the coast of Maine, marked by long crooked fiords, rocky shores and islands, cliffs and steep pebbly beaches; it is like and yet unlike the California coast, which also is bold and rock-bound, but which for hundreds of miles presents an almost unbroken front to the waves of the Pacific. Few islands adorn it, and the bay of San Francisco is the only harbor that leads deep into the land. Strongly contrasting with these is the coast of Virginia, where beaches of gray sand stretch for miles in smooth curves, a barrier between the waves of the Atlantic and the lagoons which fringe the low margin of the Coastal Plain; or the marshy shore of Louisiana, including the great delta of the Mississippi, girt with muddy spits and bars which scarcely rise above the Gulf.

The character of a shore is worked out by the sea according to the aspect of the land against which the waves break. The shore is a line along which the waves attack. In the contest the sea is active, whereas the land is passive; and the edge of the land is shaped by the sea until it becomes even, perhaps, if the work goes on long enough at one level.

When a coast, migrating, takes up a new position, the shore is said to be young. Its shape is then determined by the contour of the land. When a shore has been so long established along a constant level that it is adjusted to the waves and currents of the sea, it is said to be aged. The coast of Maine remains young; that of Virginia has become aged. Youth and age are here distinguished not by the lapse of time, but by the development which may be more rapid

along low lands and upon softer rocks than across high lands and more resistant rocks.

The attack of the sea is delivered in a horizontal plane, the plane of sea-level, and in a zone a few feet above and below. The agents of attack are waves driven by the winds, sweeping rocky material and sand with them; they are checked on shallows and breaking strike blows, which often have great force. If the blow is struck against a very gentle slope under water, it glances with relatively little effect. If it is delivered against a sand or pebble beach, the sands or pebbles are redistributed till they attain a slope on which an advancing wave sweeps up only what in retreating it carries back. This is a slope of equilibrium for waves of that capacity to move the materials. If the shore be composed of coherent rock, whether soft or hard, the blows of the waves cut it away in the zone of their delivery. Any slope is chiseled away at a definite level. All the rock above that level is undermined and from time to time falls into the sea. Thus two facets are carved upon the land; the one a level bench or terrace marking the lower limit of the waves' effect, a few feet below water-level; the other a steep face or cliff from which the latest fallen rock has parted. The effectiveness of wave action depends in part upon the depth of water near shore, in part upon the strength of the waves, and in part upon the firmness and height of the land. Across low lands of slightly coherent rock, a strong sea may rapidly cut its shore until the shallows on its wave-carved terrace break the force of the attack. If then simultaneously the relative level of land and sea changes, so that the water grows constantly deeper on the terrace, the advance of the sea may progress unchecked over a wide expanse. The wave-cut terrace then becomes a broad submarine surface, which is technically described as a plane of marine transgression. It is known that such a plane was thus wrought across western Maryland, Pennsylvania, Ohio, and other central states as far as Wisconsin in an early geologic period, the Cambrian.

In thus planing down the land, waves receive and deliver to the sea the loosened rock. Their work is twofold; they roll and grind the coarser, while they sort out and sweep away the finer materials.

The onrush of the wave is succeeded by the outflow of the undertow, and as the former is constantly repeated the latter is a continuous, pulsating current. Stirred up in the dash of a breaker, sand and clay are seized and swept out by the undertow. The mill of the waves effectively grinds, efficiently sorts, and delivers its grist to the sea. The grist is assorted sand and mud, which go to make up some sedimentary rocks.

WORK OF RIVERS.

Under the influence of the weather rocks disintegrate and decay. Some constituents remain insoluble, forming soil, others pass into solution. Soil and solutions are both received by streams from rivulets, and carried down eventually to the sea. Unceasing as the dash of the waves on the shore, the work of rivers gradually moves mountains. In common parlance this is a figure of speech, but it is not so in geology. It is a simple fact, apparent when one contemplates a brook and considers how constantly it is restored by rains, while the inert rocks decay and waste away.

The effect of moving mountains, even though grain by grain, is to level down the heights to a lowest possible slope. As water will not flow on a level, so there is a minimum fall which at least is necessary to cause sediment to flow with water. If the fall becomes less, the sediment sinks. Below this very gentle slope, which at its outer margin extends beneath the sea, streams cannot reduce the land. The process by which heights of land are leveled, called erosion, progresses slowly as it nears accomplishment. The ideal lowest possible slope, which is called a base-level, is perhaps rarely reached; but plains of very low relief have resulted from time to time.

As rivers carry down the waste of land, it becomes tributary to the sea. Each stream delivers a proportion according to the extent and character of its drainage area. From heavily-loaded rivers deltas are built out against weak waves, but relatively strong waves and currents seize the tribute and sweep it off. A delta also ultimately ceases to develop and, unless submerged by subsidence, becomes the spoil of the waves.

The work of rivers being recognized from the facts of the present, it is recognized that the same work was done by rivers which long since disappeared from the face of the earth, and their existence is sometimes vaguely recorded in sedimentary rocks.

Illustrations of Sedimentation.

Sedimentation is that process by which the waste of the land is distributed and deposited beneath the sea. The work of distribution is performed by currents of the sea which are caused chiefly by the winds, and the settling of the waste is due to gravitation. The winds are driven by the sun's heat and directed by the revolution of the earth, and thus like erosion this process of sedimentation is the work of the sun and gravitation.

SANDS ON THE ATLANTIC SHELF.

Waves roll in from an uninterrupted course of several thousand miles upon the coast from Long Island to the Carolinas. Over the stormy North Atlantic easterly winds are frequent and powerful, and the waves they drive so far strike the coast with great force. Across broad stretches the shore is low with intervening bluffs of moderate height. From the bluffs the waves remove gravel, sand and clay, which they sweep along shore, building barrier-beaches before the lowlands and across shallow bays.

The rocks opposed to the powerful waves are incoherent. They are deposits of various sorts, but all have been subjected to influences of weather and of water so long or so often in the past that they have become mixtures of clay and sand which but slowly undergo further decay in the process of erosion. Easily removed, they may be sorted and distributed, and the assorted deposits consist of the most durable minerals.

Sorting and distributing begin the moment the materials fall into the line of breakers. The currents along shore transport them, dropping out the coarser sands when the weight of the particles exceeds the carrying power of the current; and the waves seize upon these sands and build beaches. The shore currents sweep on with the finer

sand and clay until the sediment sinks into the undertow, which flows seaward down the slope of the ocean's bottom. That slope is very gentle for 50 to 100 miles from shore and then grows steeper. Upon the broad shelf the water deepens gradually to 100 fathoms; beyond it becomes generally more than 3000 fathoms deep. The undertow and off-shore currents efficiently carry the fine clay out to the margin of the shelf, but there the movement is checked by the great body of deep water and the load of clayey sediment is deposited. Between the outer zone of clay deposits and the inner limit of beaches, the shelf is spread with sands, coarser near the shore, finer toward the ocean. These sands have been beaten on the beaches, worn, tossed, and washed. They are concentrated till they consist of little else than quartz and fragments of hard shells. Near shore they are deposited by currents which eddy and pulsate under the influence of tides and storms, producing irregularities in the coarser beds; further off-shore they settle out from gentler and steadier currents, which lay them in even beds. There are strata of white sandstone among the rocks of Maryland, which are composed of beach-worn sands deposited off a shore resembling the present Atlantic coast.

LIMY MUDS IN THE GULF OF MEXICO.

The bottom of the Gulf of Mexico is covered with fine-grained, limy mud. The waters of the Gulf move as part of the great South Atlantic ocean current, which enters through the Strait of Yucatan and passes out through the Strait of Florida. The current flows from equatorial regions and is warm; it sweeps by the mouths of the Amazon and Orinoco and is charged with immense quantities of sediment and of substances in solution which those rivers bring to the sea. Much is deposited in the Caribbean deeps, but the stream enters the Gulf still charged with fine silt and there receives the contribution from the Mississippi. Circulating in eddies the waters lose their sediment, which is distributed somewhat evenly over the bottom, constituting a fine ooze. The warmth of the water is favorable to the development of manifold forms of floating marine life, which take carbonate of lime from the water and dying contribute it to the

volume of sediments. Thus the ooze becomes limy or calcareous through organic agencies. It may become limestone if the proportion of lime be sufficient, or calcareous shale where the inorganic sediment predominates, or limestone and shale in alternation where the warm life-bearing waters of the ocean current meet the occasional muddy floods of the Mississippi. Conditions similar to these prevailed widely throughout the interior sea of America during several distinct epochs of Appalachian history, and they are recorded in limestones and shales of the sedimentary rock series.

Illustrations of Deformation.

Deformation is the name given to that process which results in changes of form of the earth or of some part of the earth. Although changes of form which have gone on in the past or which are going on now have been observed in all lands, the movements which result in change of form and the causes that effect them are not yet clearly understood.

Movements whose effect is apparent in rocks are movements of the crust of the earth, the word crust being used to signify that portion of the earth which lies within a depth of a very few miles below the surface on which men live. Not long since it was generally believed that there was a crust which, having solidified, was distinguished by its solid condition from a molten interior. Many competent thinkers now incline to the hypothesis that the interior also is solid, and not distinguished from the exterior except by physical and chemical differences due primarily to pressure and secondarily to heat. But observation can apply only to an external shell some 5 to 10 miles deep, and this may conveniently be called the crust without defining its relation to the interior.

Movements of the crust may probably occur in any direction, but they are manifested in effects which may be attributed either to vertical movements, that is those in the direction of a plumb-line, or to horizontal movements, that is those in the plane of a water-level surface. Some of the effects of these two classes of movement and the manner in which they are interpreted may be stated.

EXAMPLES OF VERTICAL MOVEMENT.

In the vicinity of Washington and Baltimore excavations here and there expose granite, or an allied rock, beneath a stratum of coarse gravel which was spread by waves breaking along a former shore. At present the bed of gravel lies high above the sea. In relation to the sea it has been raised to its present elevation by a vertical movement of the crust.

The granite beneath the gravel is of a coarse crystalline texture produced in rocks once molten and cooled very slowly beneath the surface. The allied rocks, schists, are divided by many partings into thin leaves, usually standing on edge. This peculiar lamination associated with certain crystalline characteristics is an effect of mechanical and physical alteration under conditions of enormous pressure. It is developed only at great depths. If these characteristics of the granite and schist are correctly interpreted the rocks beneath the gravel bed have risen many thousand feet relatively to sea-level to reach their present position. This rise is equivalent to the growth of a very high mountain range, but it may never have resulted in a great elevation above sea as the atmosphere constantly weathered off the rising surface of the land. The height of any mountain range is the difference between the total uplift above sea-level and the amount eroded. During long epochs the uplift about Baltimore was very slow, and may not have resulted in great heights; yet during other episodes accelerated development may have produced conspicuous ranges. The most significant fact is the vertical movement in the earth's crust.

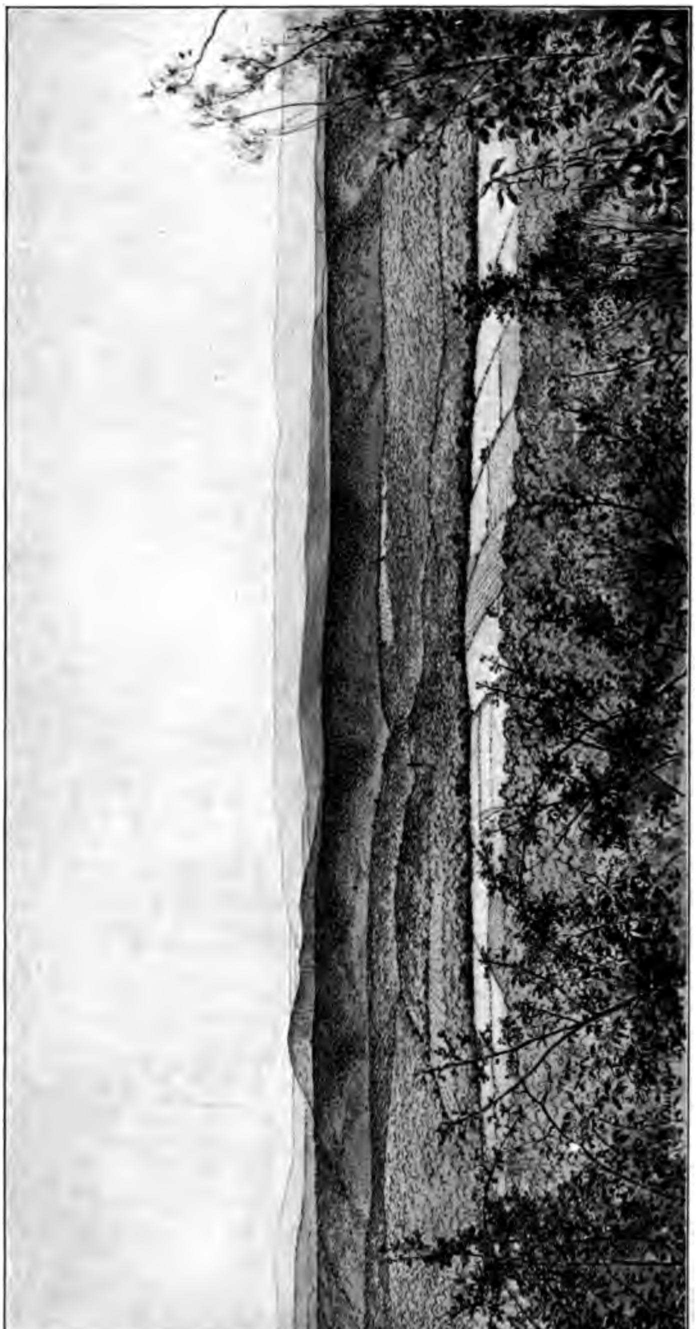
Mountain ranges are the expression of relatively rapid uplift, which may result either from direct vertical movement or indirectly as an effect of horizontal movement. The Appalachian mountains have long been interpreted as caused by wrinkling of the earth's crust, an effect of horizontal movement, and such an Appalachian range probably existed formerly. But these mountains of to-day are a result of direct vertical movement, as may be explained briefly here, although the detailed account belongs to a description of the later events of geologic history in the province.

Being constantly exposed to the destructive attack of the atmosphere, mountains diminish in mass as soon as they cease to grow vigorously, and ultimately they are worn away. Prolonged as the process of destruction may seem to man, it is a brief geologic event. All existing mountains have developed during the later geologic periods; some are still growing; others are passing into their decadence, becoming hill regions, and will become plains. Mountains rise from plains and give place to plains.

During a recent geologic period, the Cretaceous, the site of the Appalachian mountains was an extensive plain from Canada to Georgia, from Maryland to Ohio. Lines of that surface are seen in the long level crests of North Mountain, Sideling Hill, and the Alleghany Front. The former plain has been elevated unequally, most along the axis of the highest ranges, little or not at all about the Atlantic and Mississippi margins, forming a very broad dome about 4000 feet high. In that dome rivers and rivulets have engraved the valleys of the Appalachians along softer beds of rock, while the harder still maintain their heights as ridges.

The uplift developed and has been sculptured to its present aspects since the Cretaceous period. Before that period, as will be shown later, the wrinkling of the earth's crust, to which the growth of the mountains has been attributed, was completed, and whatever ranges resulted from the wrinkling had been worn away. The present Appalachians, therefore, are not an expression of that horizontal movement (wrinkling), but of a vertical uplift, which is of later date.

Subsidence of the earth's crust is a vertical movement which is the reverse of mountain growth. The evidences are many that areas of wide extent as well as more limited ones have subsided with reference to sea-level from time to time throughout all the known geologic past. Lands have sunk beneath the sea, causing the shore to migrate far, and upon the newly established sea-bottom sediments have accumulated many thousand feet thick. Upon successive strata frequently occur the marks of shallow water, proving that the deepening basin was as rapidly filled. The thickness of strata gives a measure of the amount of subsidence, and in mountains the occurrence of strata



Potomac Valley in the Distance.

Round Top.

Tonoloway Ridge.

North Mountain in the Distance.

Drawn by S. B. Nichols from a Sketch by the Author.

VIEW FROM SIDELING HILL, LOOKING EAST.

formed in a subsiding basin is a demonstration that the downward movement in such a case was succeeded by one in an upward direction.

EXAMPLES OF HORIZONTAL MOVEMENT.

Movement of a segment of the earth's crust in a horizontal direction appears to be indicated by the folds which occur in strata that were once flat. The familiar illustration of a fan may make this clearer. When the fan is opened wide it is flat, and the outer sticks are far apart; when it is partly closed the paper is thrown into folds, and the outer sticks have approached. Folds which in some respects resemble those of a fan occur in beds of limestone, of coal, and of other rocks, which were originally spread flat. It would seem that the outer edges of the folded zone had approached, as do the outer sticks of a fan. In the Appalachian mountains there is such a folded zone, which before it was folded, was approximately 100 miles or more in width and, being folded, is now 65 miles wide. That is to say, the outer limits of the zone have come nearer together by 35 miles. Whether, as has been commonly held, this approach be due to shrinkage of the earth or not is not here discussed. The fact of horizontal movement within the zone of folding is established.

The movements that resulted in Appalachian folding occurred during the ages whose events are to be described, and the conditions leading up to and attending the development of the folds will be set forth so far as they are understood. The mechanical laws which govern the location and size of folds in strata are in fact simple, although the effects are so stupendous in magnitude that the mind may at first find them incomprehensible. A series of strata twenty thousand feet thick may fold like a pile of paper, if the forces are adequate.

RELATIONS OF THE THREE PROCESSES.

Deformation, erosion, and sedimentation are related in so far at least as the first provides conditions essential to the activity of the other two, and the second supplies the materials for the last. That is: Deformation initiates an activity which results in erosion and sedimentation successively. Many theories have been advanced to show

that erosion and sedimentation result in deformation, and that the cycle of processes is complete, but the conclusion has not been demonstrated. Deformation may be an effect of an independent cause, or causes, which would be the more remote cause of all three processes. As the events of Appalachian history followed from the activity of the three processes, the relations of the processes may advantageously be more fully explained.

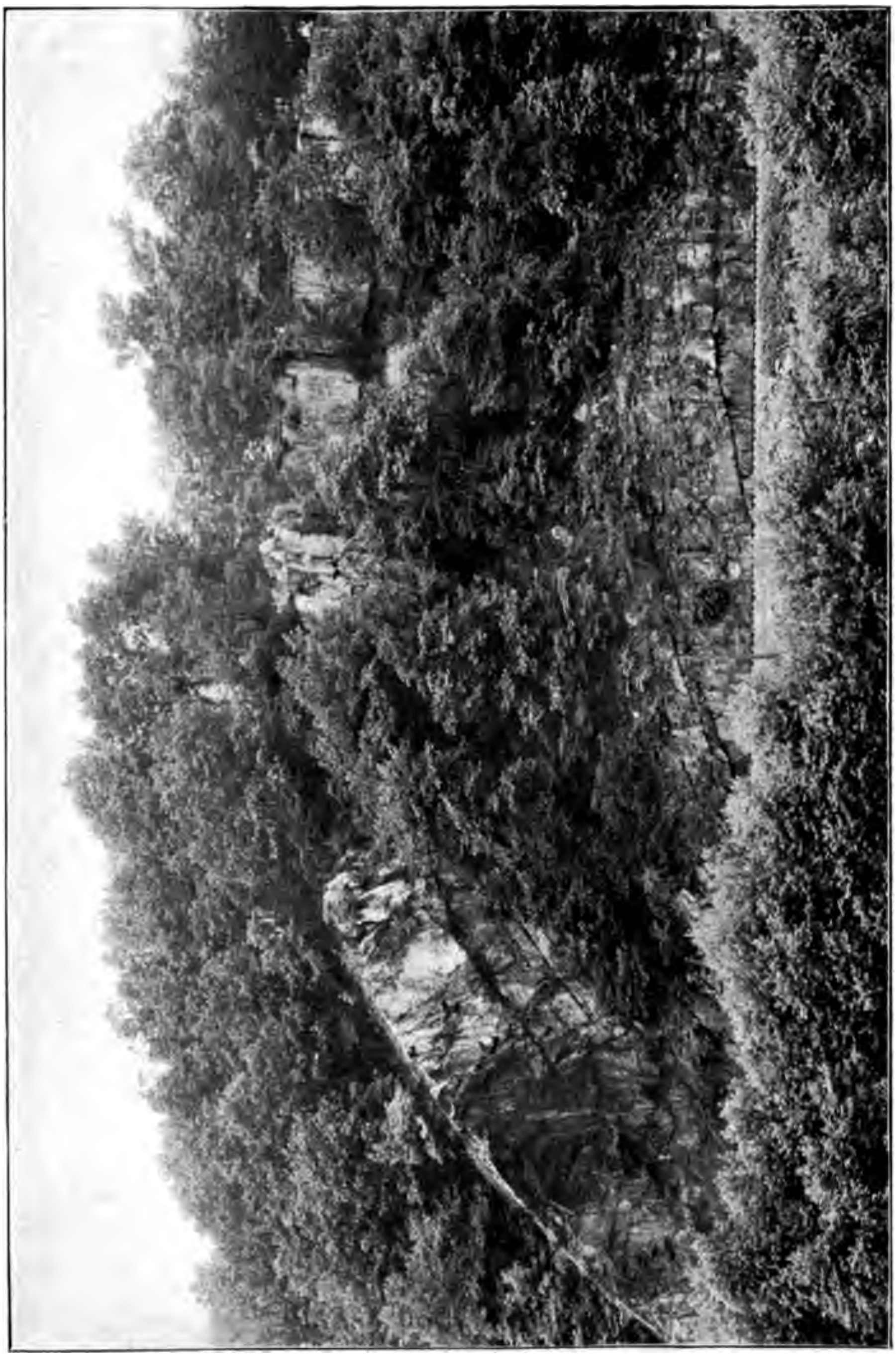
The oceans are contained in broad basins within which are profound deeps, and the continents are wide elevations above which mountains rise. The larger inequalities of the surface of the earth are so distributed that two-fifths of the total area lie between 11,000 and 16,000 feet beneath the ocean, with a mean depression of 14,000 feet below sea-level; and one-fourth of the entire surface falls 1000 feet below and 5000 feet above sea-level, with a mean elevation of 1000 feet. The former, that great expanse lying approximately 14,000 feet below sea-level, has been called the oceanic plateau; the latter is known as the continental plateau. The facts are graphically set forth in the following diagram, which was first prepared by Gilbert,[1] after data assembled by Murray.

The inequalities are the net result of deformation during geologic ages. As the margin of the continental plateau is submerged, the oceanic basins are now more than filled by the sea. If in consequence of deformation the basins should deepen, the waters would recede from the continents; or apparently the same result would follow if the continental plateau should rise. But there would be a distinction between the two effects, in that a deepening of the sea basins would affect the shores of all continents alike, whereas the uplift of one continent would probably not be shared equally if at all by others. There is evidence to suggest that the oceanic basins have deepened materially during certain episodes of the earth's history, and there are facts to prove that continental masses have been raised. Mountain uplifts have occurred even more frequently and more energetically.

The effects of deformation which result in the elevation of moun-

[1] Continental Problems, Bulletin G. S. A., Vol. IV, pp. 179-190, 1893.

GENERAL VIEW OF ARCH OF ORISKANY SANDSTONE ON NORTH BRANCH OF THE POTOMAC NEAR JUNCTION WITH SOUTH BRANCH.



DETAILED VIEW OF ARCH OF ORISKANY SANDSTONE ON NORTH BRANCH OF THE POTOMAC NEAR JUNCTION WITH THE SOUTH BRANCH.

tain masses or continental masses above the sea thereby favor the process of erosion, whose tendency is to grade down the land. If an uplift be accomplished, it will be graded down by erosive processes in time, no matter how great its magnitude. And when the degradation is completed to a plain at the lowest possible slope, then the activity of mechanical erosion pauses.

A principal result of erosion is the preparation and delivery to the sea of land-waste, with which sedimentary deposits are built up. The

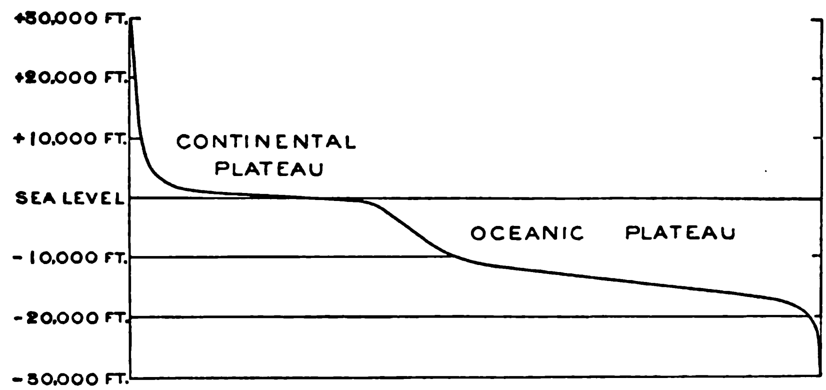


FIG. 1.—Generalized profile, showing relative areas of the earth's surface at different heights and depths. The width of the diagram from side to side stands for the entire earth's surface. The curve shows the relative extents of the continental and oceanic plateaus and adjacent slopes. These relations are expressed independently of the distribution of land and sea.

rate of accumulation of sediments depends upon the rate of erosion, though indirectly in many instances; but in general it is true that when lands are prevailingly low, sediments accumulate slowly, and sedimentation may fail when erosion becomes inactive.

The three processes may be thus characterized: Deformation initiates activity; erosion destroys uplifts; sedimentation reconstructs rocks and records events of geologic history.

PALEOZOIC HISTORY OF MARYLAND AND ADJACENT STATES.

The Point of View.

Geologic history is an account of development; it may be of the development of continents and oceans, of lands and seas, of mountains and river systems, that is of the physical history of the earth; or it may be of the evolution of plants and animals, that is a history of the organic life of the earth. Organisms obey a general law of change. The nature of the variation in any case is an effect of inherited tendencies and of an effort toward adaptation to physical environment. Environment is modified in epochs which are brief as the earth's history is measured, and the changes react on faunas and floras. Thus in order to understand the life history of the globe it is necessary first to know the physical history.

This article is a contribution to the study of the physical changes only. It is an attempt to interpret the mechanical characters of certain sedimentary rocks, in the order of sequence as they occur, and in accordance with the effects of deformation, erosion, and sedimentation now observable on continents and about their shores. Some of the episodes which are comprised in the review are the growth and wasting of several mountain systems, the expansion of plains of continental extent and their submergence beneath widening seas, the construction and migration of extensive coastal plains, the upfolding and dislocation of sedimentary strata from 2 to 6 miles thick in a zone a hundred miles wide and fifteen hundred miles long, and the withdrawal of the sea from the province over which it had circulated during many million years. The magnitude of the phenomena is co-ordinate with the lapse of time, and both surpass man's grasp, but the evidence of the facts is unmistakable in all the broader relations.

The Place and Time.

The scene of this history is eastern North America, comprising a region between the present Mississippi Valley on the west and an

LEGEND

Ca

*within which early Cambrian
iow outcrop and which was sub-
at that time.*

Ce ?

*is probably submerged in early
ian time.*

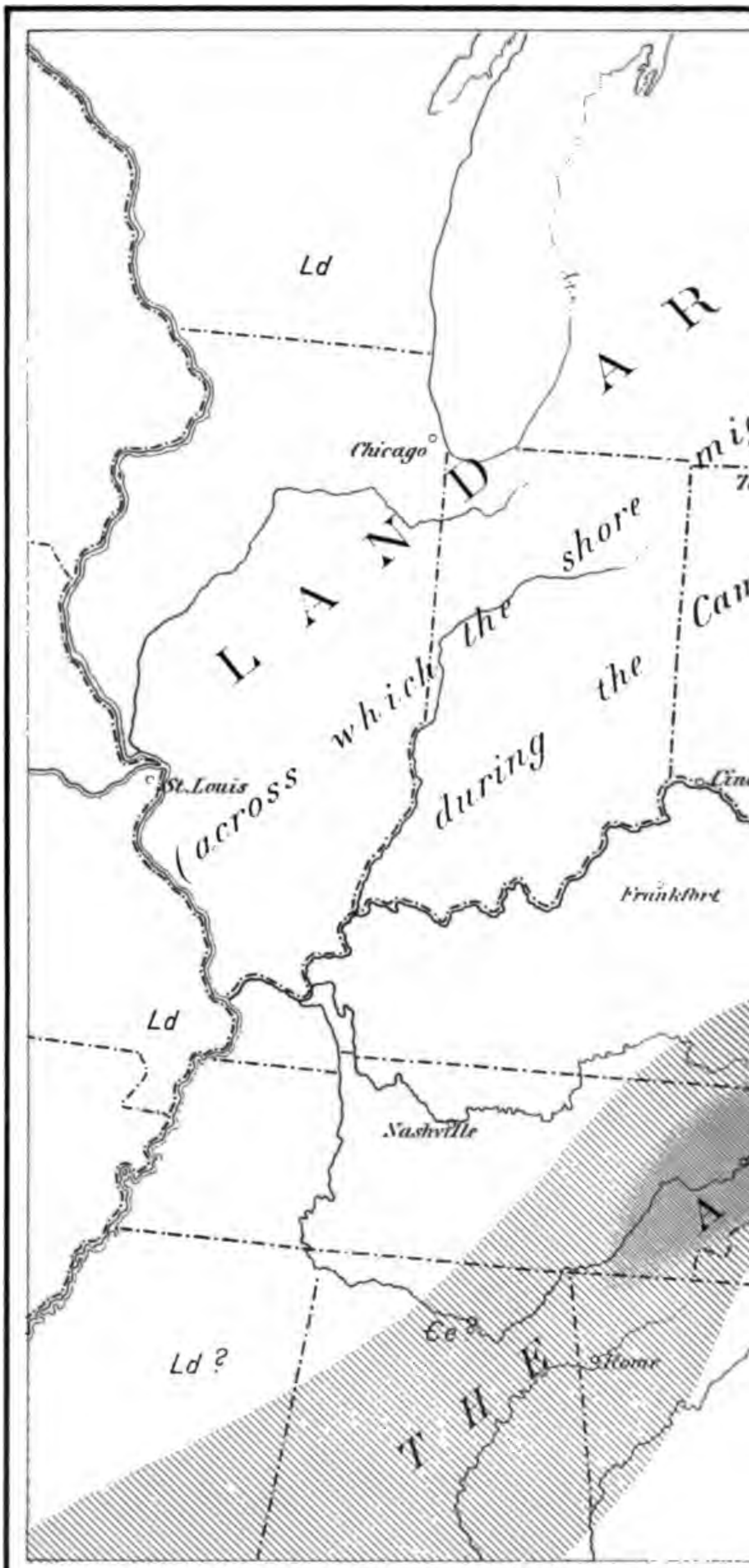
Ld

areas in early Cambrian time.

Ld ?

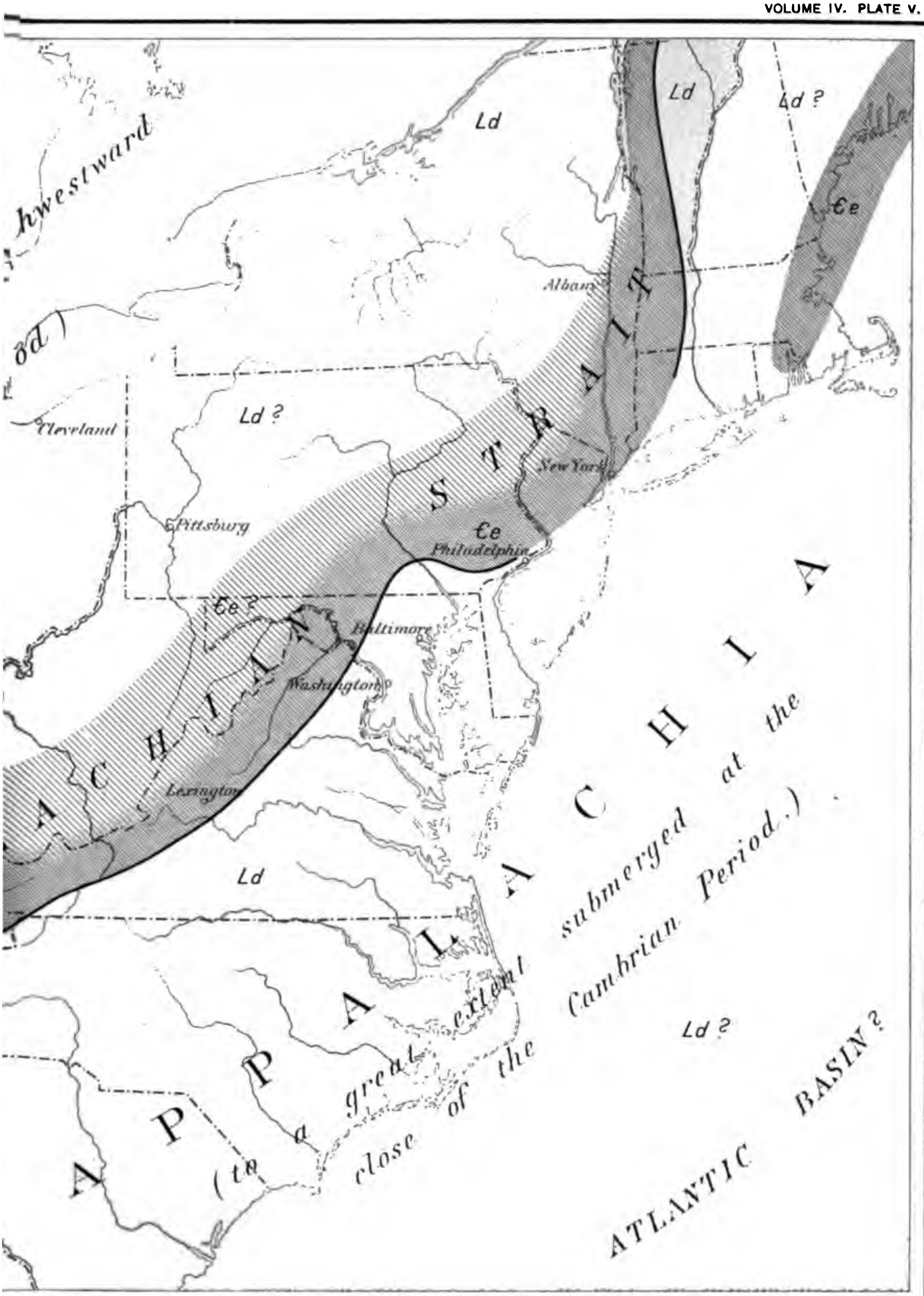
*ible land areas in early Cam-
ne.*

*parallel to outcrop of the basal
ormity and probably parallel to
id of early Cambrian shores.*



Based upon the
Geologic Map of the U.S.
by W J Mc Gee, 1893, and
Cambrian maps by
C. D. Walcott, Bull. 81,
U. S. G. S. 1891.

Geo



the Eastern United States
early Cambrian Time

A. Hoen & Co. Lith. Baltimore

Bailey Willis
1899

unknown limit on the east where now the Atlantic rolls. The region comprised a sea and a land. The sea lay west of the land; the land stretched eastward beyond the present extent of the continent. The shore along which the western sea met the land migrated during ages far eastward and again far westward with many minor oscillations back and forth, and the areas of land and sea shrank and expanded each in opposition to the other. The land may be called the continent of *Appalachia*. The sea was the mediterranean of North America.

The time of this history covers the Paleozoic era, the era of ancient life, which is distinctly recognized as a grand division of geologic time represented by rocks known in many parts of the world. The Paleozoic era was many million years, how many cannot safely be estimated. Since its close other millions of years, probably fewer, have elapsed. Before its earliest episodes, longer time than has since passed had been occupied by events which are recorded in older rocks. Thus, the era of ancient life, the Paleozoic, is an early part of the later half or of the latest third of geologic history.

Rocks of the Paleozoic era are recognized by the fossils they contain, most of which represent creatures that lived on the sea-bottom. Except the vertebrates, which, however, appeared as fishes early in the era, the several types of organic structures existed in varied development at the beginning of the Paleozoic, and their evolution has since involved thousands of species and hundreds of genera, of which but a very few survive unmodified. The development successively of different forms and the corresponding disappearance of groups of preceding types occurred, perhaps gradually on the whole, but in limited districts where conditions varied rapidly with sharper distinctions between the older and newer forms. These distinctions correspond to changes in the nature of the rocks, which were themselves related to changes in the physical conditions of the sea; and the variations in the organisms are due to an extinction of the forms which were too conservative in their habits and to the immigration or development of others that could adapt themselves. The failure of any type to perpetuate itself may be due to misdirected development under stimulus of too favorable an environment, or in cases of unfavorable environment to inadaptability or weakness.

According to the facts of the three most marked episodes of variation of species the Paleozoic era is divided into four periods, the Cambrian, Silurian, Devonian, and Carboniferous, named in order from earliest to latest, and the close of the Paleozoic era is defined by the general disappearance of the ancient forms of life, and by the appearance in succeeding strata of types more nearly allied to those of the present. For more detailed information on the facts which determine the classification of geologic events, the reader is referred to textbooks on geology.

Appalachia before the Paleozoic Era.

THE PRE-CAMBRIAN ERA.

The rocks of pre-Cambrian Appalachia fall into four classes, which differ in their genesis and accordingly signify distinct episodes of history. These are the schists, the granites and allied igneous rocks, volcanic rocks, and sediments. The schists are the oldest and their origin is in many cases obscure. They may have been in part sedimentary, but are known to have been to a large extent of igneous origin. Their significant characteristic, however, is the arrangement of their minerals in such manner that the longer axes of the crystals are parallel. The minerals which have assumed a parallel relation are not the original minerals of the rock as it first formed, but are those which have developed during chemical changes under conditions of extreme pressure. This structure gives to the schists their tendency to cleave in thin layers along parallel planes, and is one which is acquired only at great depth in the earth's crust. Therefore whatever may have been the origin of the rock from which the schists are derived, it is certain either that it formed at great depth or after having been consolidated near the surface was deeply buried. The granites and the allied rocks exhibit a coarsely crystalline texture uniform throughout large masses, which is peculiar to rocks which have been molten and cooled slowly. The conditions for such cooling exists only at some distance beneath the surface, and thus the granites also indicate that the rock mass of which they form a part was deeply

buried when they cooled. It will presently be shown that the schists and granites were nevertheless exposed to the atmosphere at the surface of the land in early Paleozoic time and that they had, therefore, risen from the depth at which they developed their characteristic structures. Similar phenomena of granitic intrusions took place late in the Paleozoic era in New England, and at still later dates in the Rocky Mountains and Sierra Nevada. The uplifts by which the deeply buried rocks were raised to be bared by erosion constituted mountains in pre-Cambrian time, probably as they did late in the Paleozoic and do now. Thus the process of mountain growth is seen to be one of great antiquity.

The pre-Cambrian volcanic rocks still retain structures, such as lines of flowing, peculiar to lavas which have been poured out in a molten condition and cooled at the surface of the earth, and they tell of volcanoes whose activity was intense and which were widely distributed. In their chemical composition as well as in their internal structures these rocks are closely related to lavas erupted in later times, and the resemblances serve to strengthen the inference that the western portion of Appalachia in pre-Cambrian time was the scene of events since reproduced in the western regions of North America.

The existence of high lands was favorable to erosion, and an accumulation of sedimentary strata in adjacent seas was a necessary consequence. Those strata were subsequently deeply buried under Paleozoic formations, and if now exposed to view appear distorted as parts of mountain masses. Their relations to later sediments are obscured and, as the pre-Cambrian rocks very rarely contain fossils and none have been found in their supposed representatives in the Appalachian province, it has not been possible to identify them positively. The strata now considered to be the oldest of the Appalachian series may be pre-Cambrian or Paleozoic. However, in the Smoky Mountains of North Carolina is a group of more or less altered shales, sandstones, and conglomerates which is probably of pre-Cambrian age. It was named the Ocoee group by Safford, who correctly perceived its probable great antiquity, and it has been traced into

Georgia by Hayes and into Virginia by Keith. Where the strata of the Ocoee group occur in contact with the still older schists and granites it may be seen that the sediments are composed of the slightly sorted and rearranged detritus of the more ancient rocks, as sometimes happens along a shore. The story of that coast may not be written until the distribution and relations of the Ocoee are more thoroughly known, but it is probable that the facts bear witness to the positions of the western shore of Appalachia in its migrations, during the later epochs of pre-Cambrian time.

At the beginning of Paleozoic time Appalachia had thus already acquired a complex rock structure, and the surface of the land corresponded to the truncated bases of earlier mountain ranges. There is reason to believe that it was hilly, but not elevated, and that the rocks were deeply decomposed as their representatives now are throughout the Piedmont region of the Atlantic border. The interior sea washing the coast of Appalachia on the west was then a strait, probably not more than 100 miles in width and 1,500 miles long, extending from the Gulf of St. Lawrence along the line of the Champlain trough to the great Appalachian Valley of New York, Pennsylvania, Maryland, Virginia, and Tennessee, into Alabama. Its southern or southwestern connection cannot be traced, and its western shore is not accurately determinable, but its eastern side lay not far from the present line of the Blue Ridge through Maryland and Virginia. The absence of pre-Cambrian and early Cambrian sediments across the central states shows that there a land area extended, and it was bounded on the west by a second narrow sea whose sediments now form part of the mountains of British Columbia, western Montana, Idaho, and Utah. Thus the continent of North America was in that early day divided by two straits into three continental areas; the eastern continent, Appalachia; a central land extending to the Rocky Mountain strait; and a western whose farther Pacific limit is not yet made out.

Submergence During the Cambrian Period.

THE BASAL UNCONFORMITY.[1]

The pre-Cambrian schists and other rocks not of sedimentary origin are in contact with and underlie sedimentary strata from North Carolina to Canada. At the surface of contact the schists, the granites intruded into them, and dikes of formerly molten rock which cut the granite, all end abruptly. The surface was planed across their complex mass after they had acquired fixed relations, and it was probably closely parallel to a general slope developed by erosion on the Appalachian land. The strata which rest upon the old rocks are of varied character at the contact. In some places they consist of the partly decomposed minerals of granite or the less easily recognized particles of weathered schist; and elsewhere the sediments were clayey or of quartzose sand. The granitic sands are often deposited on or near a granite mass from which they were derived, and of the other sediments those whose original character can be recognized lie frequently in similarly close juxtaposition to their parent rock. The clayey beds and quartz sands were partially washed and sorted from the more thoroughly decomposed schists and granites. Thus the source of these sediments was the weathered surface of various rocks, the land surface of Appalachia, and the waters which received and rearranged them played close to the source. These conditions are associated only along shore, and where this contact of the sediments upon the older rocks is found, there was once a shore with bluffs and beaches and bars.

The surface of contact is an unconformity which marks a great interruption in the geologic record—the schists and granites are very much older than the sediments, as has been indicated in describing

[1] An unconformity marks an hiatus in the geologic record. It is that relation between a sedimentary stratum and any older group of rocks which exists when the older rocks have been involved in uplift and subsidence prior to the deposition of the younger stratum. The movement may have been effected without disturbance, or the rocks may have been completely sheared and folded. The rise may have resulted in very slight effects of erosion or in the dissolution of mountains. The time corresponding to the hiatus may have been a brief episode or a great era.

the pre-Cambrian history—but the close of the hiatus is not everywhere of the same date. This is determined by the age of the strata deposited on the eroded surface of the older rocks. Throughout much of the Appalachian Mountains, the oldest strata next to the pre-Cambrian rocks contain fossils which belong to very early, generally low, types of life, and by which the strata are identified as of early Cambrian age. Elsewhere, strata of the Ocoee group lie upon the pre-Cambrian. They contain no fossils but, as has already been explained, they are probably older than the Cambrian.

An explanation of the different dates marked by the close of the hiatus is not far to seek. Where the Ocoee strata rest on the old schists and granites, there was the shore of the sea during an episode of that date; where the early Cambrian sands were deposited in a similar relation was the shore of a wider sea, which at that later date spread further upon the Appalachian land. In technical phrase the Cambrian strata overlap the Ocoee strata in the greater part of the province. Hence we may draw the conclusion that Appalachia had for some time been subsiding with reference to sea-level when the forms of life which mark the early Cambrian appeared in the waters of the adjacent strait.

CAMBRIAN STRATA.

The sequence of strata deposited during the Cambrian period may briefly be described as composed of coarser sediments at the base of the series followed by finer sediments above; or as consisting of mechanical deposits in the lower part mingled with but little material of organic or chemical origin, and in the upper part chiefly of organic or chemical sediments with only the finest mechanical products of rock disintegration. The lower strata are conglomerate, sandstone, and sandy shale, the upper are calcareous shale and limestone. Generalizing local details which mark fluctuating conditions in limited districts, the above statement is true of the entire Appalachian province from Alabama to Canada, and from that comprehensive fact the nature of the geographic changes is broadly to be inferred.

When the early forms of marine life, which indicate the beginning

of the Cambrian period, appeared along the shore of Appalachia, that continent was subsiding, as has been stated. The coast of a sinking land is characterized by features which cause peculiarly local and varied sediments along a narrow littoral zone. Valleys, being flooded by the relatively rising sea, become bays or estuaries like the Chesapeake. If they are extensive they receive and retain all the sediment brought down by tributary rivers, as is now the case with the great volumes contributed by the Susquehanna, the Potomac, and other streams flowing into Chesapeake Bay. It is floored with "blue mud" almost to Norfolk, but beyond the Capes the ocean bed is of sand.

Between the estuaries extend higher lands, as peninsulas, and against their headlands waves beat, carving sea cliffs, from which pebbles and sand are distributed over the adjacent sea-bottom. The powerful waves of the Atlantic abrade, sort, and carry this material very efficiently, and our coast is bordered with clean, sandy beaches; but the waves which broke on the shore of Appalachia were weak. In many localities they failed to sort the decomposed rock, which they washed gently to a resting place near its source. Elsewhere beating more strongly, or aided by local currents, or having the partly sorted detritus of an older sedimentary rock to handle, the waves spread clayey sands or sands consisting chiefly of clean quartz. Thus along the subsiding shore at any time, deposits of river mud accumulated in estuaries, and wave-wrought, coarser materials of various kinds were spread along the coast-line. In addition to the variations along the coast, there was a more uniform change in the character of the deposits from the coast seaward. Coarser sands gathered near shore, and finer sands and clay subsided farther out.

Although the general movement of Appalachia was a sinking one, there were episodes when the continent stood at a constant level or even rose with reference to the sea. In the former case the rivers silted up the estuaries and the waves accomplished more thoroughly the abrasion and sorting of detritus along shore. In the latter case, as the estuaries again became valleys, the rivers resumed their courses and, scouring out the accumulated mud, swept it to the sea,

while the waves, withdrawn from their previous advance, washed over the sediments they had most lately distributed. Such oscillations of level may account for the alternation of coarse and fine detritus in the mechanical sediments and for variation in the degree of concentration of sands, which sometimes consist of minerals easily decomposed mingled with quartz, and again of concentrated quartz, one of the most durable minerals.

The thickness of the mechanical Cambrian sediments varies in different parts of the province. In Georgia and Tennessee, where they probably succeed the Ocoee group, their volume is great. They are there represented by the strata of Chilhowee Mountain, 2,500 feet thick, and by the Rome sandstone, 3,000 to 4,000 feet thick. In Maryland the Loudoun, Weverton, Harpers and Antietam formations aggregate 3,000 feet. In Massachusetts the Vermont quartzite is 900 feet, and the Becket gneiss possibly 2,000 feet thick.

The area over which these formations originally extended, but from which they have in large part been eroded, can never be known; nor could the land area from which they were derived be estimated, even if their original volume were calculated. But it is probable that the area eroded very considerably exceeded the area of deposit and that the tributary district of Appalachia was worn down but a few hundred feet at most to provide sediments locally 2,000 to 4,000 feet thick.

The Cambrian sandstones and shales were succeeded throughout the province by calcareous shale and that by limestone. Fine clay, the principal component of the shale, represents the waste of a deeply eroded land, or one remote from the place of deposition. Lime, the chief constituent of the limestone and an important one of the shale, was precipitated from the sea-water by organic or chemical means. The source of material of calcareous shale and limestone thus differs from that of sandstone and sandy shale, and the occurrence of the former in sequence on the latter implies corresponding changes of conditions. The effective changes were two. The one was the erosion of surviving land areas to a condition of very low relief, and the other was the extensive widening of the waters from the Appalachian strait to a mediterranean sea.

That Appalachia had become a lowland is an inference justified by the facts of prolonged subsidence and erosion indicated by the mechanical sediments, but it may be pointed out that the sequence of fine calcareous shale and limestone is evidence which confirms the inference. Where lands are high and declivities are steep, rocks are bared of soil and are broken by variations of temperature and by frost. Disintegration proceeds rapidly and chemical decay is insignificant. Where lands are low and slopes gentle, the reverse is true. There rocks decompose, forming deep beds of clayey soil. Thus different topographic aspects yield diverse sediments, and in the sequence of Cambrian strata is the record of the passing of the hills of Appalachia and on their sites the expansion of broad plains. Even the low relief of plains wastes away, though slowly, and as the surface sinks to so gentle a slope that rivers remove but little sediment, the mechanical contribution from the land to the sea fails. This is a condition to which reference will repeatedly be made to explain the character of some Paleozoic strata.

The widening of the strait eastward over Appalachia has been described. It can never be known where that migration of the coast halted, as the sediments which recorded it have been eroded, but it is by no means improbable that the sea swept over the eastern districts to or beyond the present Atlantic shore and that land areas lay still further east. The expanse of the sea westward is more definitely traceable. Strata occur along the western side of the great Appalachian Valley in Tennessee which are of early Cambrian age, and are of such relative thickness and coarseness as to indicate that they accumulated not far from the western shore of the strait of that date. Thence westward the rocks now visible at the surface are much younger. They cover the Cambrian deposits and the pre-Cambrian rocks across the Mississippi Valley to Missouri and Wisconsin; and there where the pre-Cambrian rocks reappear at the surface, the strata which rest upon them at the basal unconformity are of late Cambrian age. The absence of earlier Cambrian strata and the presence of later deposits of that period, as determined by the fossils, demonstrates the migration of the shore westward from the

Appalachian strait to Missouri and Wisconsin, a distance of 300 to 700 miles. The effect was similar to that which would now ensue if North America should slowly subside until the Gulf of Mexico and Hudson Bay were joined in one great mediterranean sea.

In this sea, whose strata still cover at least 160,000 square miles and which was probably much more extensive, the principal sediment deposited was carbonate of lime. The resulting limestone was approximately 1,000 feet in Missouri, 3,000 to 4,000 feet in eastern Tennessee, and 6,000 feet in Pennsylvania. If the average thickness be assumed to be only one-fourth of a mile, the volume of limestone covering 160,000 square miles is still 40,000 cubic miles—a mighty stratum truly. If, further, it be assumed that the percentage of carbonate of lime is but one-half, the volume of that constituent is 20,000 cubic miles, the other half being fine clay. These estimates are well within the limits of fact. Whence came, then, this vast volume of calcareous sediment and how was it deposited, organically or chemically?

The pre-Cambrian crystalline rocks of Appalachia and other land areas about the mediterranean sea, eroded contemporaneously or just before the limestone formed, first suggest themselves as the source of the lime, but it can be shown that the source is inadequate for the supply. Approximately stated, those rocks consist by weight of about 80 per cent of silica, alumina and iron oxides, which all go to make up the insoluble mechanical constituents, and of but 5 per cent of lime. To the latter we may add the same proportion of magnesia, which passes into solution and may be precipitated with it. If in this rough estimate we pass lightly from measures by weight to measures by volume, we should have 8 feet in thickness of sand and clay deposited for each 1 foot of lime over the same area. Or, considering that sand and mud are deposited chiefly along shore, whereas the lime is spread widely over the sea-bottom, the former should be several times thicker in proportion. In Cambrian strata no such volume of sandstone and shale is known or is likely to have existed; therefore, the contemporaneous contribution of the lime from Appalachia and other lands to the mediterranean is inconsistent with

facts. But the difficulty vanishes if the idea of a contemporaneous source on land be abandoned for the assumption that the lime had been derived from lands eroded during pre-Cambrian ages and had been stored in the waters of the ocean. It must then, however, be shown in what manner the character of the mediterranean specially favored the precipitation of lime and so caused the unusual deposit of limestone. This can best be done by reference to appropriate organic and chemical conditions.

Life flourished in the Cambrian sea. Walcott has described many species covering a wide range of forms which inhabited warm shallow waters. The limestone is fossiliferous throughout its occurrence to the extent that some remains of organisms may be found in any large mass of it, and locally they may be crowded closely in certain strata. Thus the fossils bear evidence that the waters were favorably warm and shallow and afforded food, and that living organisms produced part of the limestone. There is no doubt that any part of the lime which forms these fossils was organically deposited, but there is a large part of the limestone to which that conclusion does not necessarily apply. The fossils are generally imbedded in a crystalline or pulverulent matrix, which shows no organic structure even under the microscope. An assumption that this calcareous material was of organic origin is therefore not supported by direct evidence; the structure of the rock, on the contrary, resembles that of crystalline limestone now forming as a chemical deposit in the Everglades of Florida, or of pulverulent calcareous ooze chemically precipitated in the same waters.[1] Hence the conditions possibly favorable to chemical precipitation of carbonate of lime should be considered.

Chemical researches into the permanence of bicarbonate of lime in solution and the solubility of monocarbonate of lime thrown out of solution differ widely in results and do not at present afford satisfactory data. According to some investigators, the monocarbonate is very easily soluble; others, apparently equally careful, find it to be but slightly so. At the present time ocean water appears not to contain more than a part of the lime it might dissolve and hold in

[1] Conditions of Sedimentary Deposition. Chicago, Journ. of Geol., Vol. I, p. 512.

solution as bicarbonate, and monocarbonate of lime is apparently not chemically precipitated from it. Nevertheless, delicate and minute shells of pelagic organisms sink through as many as 12,000 feet of ocean water from the surface to the bottom, where they accumulate undissolved, and this in spite of the fact that they contain the strong solvent, carbonic acid, which is produced by decay of the organism. This fact indicates that the solvent power of ocean water for the carbonate is not great. Of the conditions which may result in the chemical precipitation of the carbonate, concentration of the solution is that which is most effective, but mechanical agitation and aëration appear to be only less so. Thus tufa, a deposit of carbonate of lime, forms where there break waves of waters which do not otherwise precipitate it. And agitation may suffice to separate out the carbonate from salt water only slightly more concentrated than oceanic brine. The European Mediterranean, being concentrated by evaporation in spite of the great rivers flowing into it, is more alkaline than the Atlantic, and the difference, though slight, appears locally to favor the formation of limestone, a crystalline deposit of which has been dredged at the mouth of the Rhone.

Frankly admitting that the composition of ocean water in Cambrian time is unknown, and recognizing the futility of comparisons with the percentage of lime in solution in the ocean to-day, we may compare the waters of the Cambrian mediterranean with those of the oceanic basins of the same time. The Cambrian mediterranean sea was broad and shallow, of such extent as to develop currents within its own area, and probably so related to the greater seas as to receive and discharge oceanic currents. Thus the waters were in circulation and influenced by the enclosing lands to eddy round and round. Of this fact the widespread distribution of the fine clay which forms part of the limestone is evidence. Evaporation of waters so circulating probably led to concentration of the salts held in solution as is now the case in the Mediterranean, and considering the great mass of Cambrian limestone which exhibits crystalline or granular rather than organic structure, it is not improbable that the effects were sufficient to cause chemical precipitation of carbonate of lime.

This great Cambrian limestone is an extraordinarily uniform, massive, and extensive bed of rock. In course of succeeding ages it was deeply buried beneath later sediments, and when strains developed in that part of the crust of which it was part it profoundly influenced the folding which ensued. Paleozoic strata of the Appalachian province are folded with remarkable parallelism and simplicity. This and other features, which have made that structure a type with which other regions the world over are compared, result from the character of the great limestone.

No cataclysm, nor even any marked change in physical conditions, closed the Cambrian period. The sea widened its boundaries to an extreme limit. Its warm and shallow waters gave the life of the time a rich opportunity for development, and there ensued material variation of species and genera. A new fauna was developed which has been called lower Silurian or Ordovician, and the period of which it characterizes the first part is known as the Silurian period.

THE SUBMERGENCE CONTINUED INTO THE SILURIAN.

The separation of certain strata, called Silurian, from those which preceded, and which are called Cambrian, depends upon the occurrence of fossils recognized as Silurian species. In the Appalachian province the plane of separation lies in the great limestone, in a position which has not yet been accurately worked out, but it is known that the lower part, perhaps two-thirds of the thickness, contains Cambrian species, and the upper part carries Silurian species. Thus the conditions favorable for the accumulation of limestone, the expanse of shallow sea and lowlands, continued for a long time after the beginning of the Silurian period.

This fact of the long-continued prevalence of the sea over interior North America in Cambrian and Silurian time is worthy of a pause in the recital of events, as it bears upon two questions of great interest—the permanence of continents and the activity of the forces of deformation. It has been pointed out that the greater inequalities of level in the earth's surface define a continental plateau and an oceanic plateau, the former lying 15,000 feet higher than the latter.

The subsidence which permitted the Appalachian strait to expand to the width of the mediterranean sea amounted to but a small part of this difference, as the land was low before submergence and the sea never became very deep. A sinking of 1,000 feet might suffice to account for the geographic changes. The degree of subsidence can hardly be considered to interrupt the permanence of the continental plateau.

The antiquity of the earth readily suggests the idea that she is growing old, that is, inactive; the forces which produced continents and mountains in the long past ages are dying out, it is said. But North America is to-day more mountainous than it was in early Silurian time. Where, in consequence of a long cessation of deformation, broad plains then extended just above and just below sea-level there are now mountains of recent growth. In tracing the Paleozoic history of Appalachia we shall find little proof that the earth has grown old, but much evidence that there have been epochs of activity in alternation with epochs of inactivity of the deforming forces.

Emergence During the Lower Silurian Period.

THE RETREAT OF THE SEA.

Throughout the Appalachian province the great limestone is succeeded by a deposit of shale. The constituents of the shale are clay and fine quartz sand. In many sections it is fine and calcareous toward the base, but sandy and coarser toward the top. In some localities it is dark brown or black with carbonaceous matter especially in the lower strata. The contact between the underlying limestone and the succeeding shale is usually a transition by interbedding of alternately more earthy and more calcareous layers, each parallel or conformable to the preceding one. At isolated points, however, and especially along the eastern margin of the Great Appalachian Valley, there is an unconformity between the shale and the limestone; it is marked by a conglomerate composed of pebbles of limestone and chert in a matrix of sand, and by overlap of thin successive strata of shale and sandstone upon the limestone. The thickness of the shale is very variable. In a line of lenses which ex-

tends from the upper Hudson Valley through the corresponding valleys of Pennsylvania, Maryland, Virginia and Tennessee, it attains a maximum of 3,000 to 4,000 feet. The Massanutten Mountain of Virginia and the Bays Mountains of Tennessee are composed largely of these great thicknesses of shale. A few miles west of this line the shale is but 1,000 feet thick or less.

These several facts of the character, relations and distribution of the shale yield a consistent interpretation of the changes from which they resulted. The constituents are those enduring minerals whose worn particles may be derived from the flood-plains of streams flowing on a lowland, or from erosion of sedimentary rocks. The transition from limey to clayey deposits with alternation of character is what should occur on a shallow sea-bottom off the mouths of muddy rivers, which were engaged in removing their flood-plains. These effects should follow from a general but moderate elevation of land, including a strip of adjacent sea-bottom. The local occurrences of conglomerate derived from the limestone indicate that islands or peninsulas developed in consequence of higher, though limited, uplifts of the sea-bottom. And the accumulation of the shale in lenses of maximum thickness shows that through subsidence along a definite zone there developed a trough which directed currents and gave special conditions of distribution of sediment. Recovering from the subsidence of Cambrian time, which, though prolonged and extensive, had been of moderate depth, Appalachia now rose slowly as a broad lowland mass which was ultimately bounded on the west by a downward bend of the sea-bottom corresponding to the present line of the Great Appalachian Valley. That flexure descended gently beneath deeper water to a trough, from which the sea-bottom rose more gradually westward to a shallow sea or, possibly, a land area, that developed at the close of this epoch or soon thereafter in Western Ohio and Kentucky. This western island is known as the Cincinnati arch.

Thus the broad Cambrian sea retreated from its eastward excursion and became a gulf, occupying Eastern Tennessee, Southern Kentucky, Eastern Ohio, West Virginia, the Valley of Virginia and

Maryland, Pennsylvania and New York, and communicating by a narrow strait or straits with the St. Lawrence Valley. Its waters did not again spread over Appalachia.

THE CHANGE OF LIFE CONDITIONS.

The broad shallows of the Cambrian-Silurian sea had afforded a roomy habitat for a large marine population. As the sea narrowed to a gulf the host was crowded into limited space and competitive conditions became severe.[1] Clear seas became muddy through addition of sediments and the food supply was modified. A great change in living forms followed. Evolution proceeded rapidly, resulting in large faunas with diversified members, and the later or Upper Silurian is accordingly separated from the Lower Silurian or Ordovician by decided differences in the forms of life.

DEVELOPMENT OF COASTAL PLAIN FORMATIONS.

A coastal plain is a stretch of gently sloping land adjacent to a coast. Its slight elevation and insignificant inequalities of surface cause the sea to advance widely upon it or to retreat broadly from its temporary margin in consequence of comparatively slight oscillations of sea-level. The effect of repeated submergence and emergence is to subject sediments which accumulate on a coastal plain alternately to the waves and to the atmosphere. They undergo weathering and washing, and the coarser particles of the harder, less soluble materials survive longest. Thus the coastal plain becomes the storehouse of pebbles and coarse sands of durable rocks. Quartz is very much more durable than most minerals and is far more abundant than any other coarse product of rock-decay, and it is stored from age to age in coastal plains.

Emerging from the retreating Silurian sea, Appalachia presented the gentle slope of a broad coastal plain. While emergence was progressing, rills and rivers, extending their courses to the receding shore, contributed the waste of the plain, which waves worked over

[1] This effect of marine recession is broadly discussed by Chamberlin: see "A Systematic Source of Evolution of Provincial Faunas," Journal of Geology, Vol. III, No. 6, pp. 602-605.

into new deposits. Fluctuations of level, which may have been strongly marked in the sandy and clayey strata of the coastal plain, are faintly recorded in the mass of shale which accumulated where the waters deepened more abruptly, but the coarser detritus was redistributed during succeeding epochs and the detailed record is lost. Nevertheless, the fact of the former existence of a coastal plain is indicated in the quartzose character of some later formations, and recognition of their earlier history serves to explain their concentrated composition.

A REMNANT OF THE SILURIAN COASTAL PLAIN.

Succeeding the great shale formation, which is taken as the last deposit of the Lower Silurian, follow coarser deposits of varied character. In general, they are red sandy shale or red sandstone, or locally, even conglomerates, upon which rests a white sandstone of large grain, sometimes pebbly. The red strata are composed of lime, clay and quartz sands, the particles being coated with red oxide of iron; the overlying white sandstone consists almost wholly of quartz. The contact between the red and white strata is sharp. This sequence is considered to contain some of the materials of the Silurian Coastal Plain and sediment from uplands deposited under varying conditions.

The presence of iron oxide as an important constituent of the red rocks is significant of the chemical dissolution of rocks containing iron minerals, from which iron was carried by streams either in solution or as a fine silt consisting of ferric oxide to the locality where it was deposited as a coating on grains of clay and sand. Students are not agreed as to the conditions essential to this process, but the following explanation may here be offered with special application, following closely the hypotheses suggested by Chamberlin.[1]

The rocks of Appalachia containing available ferriferous minerals were the pre-Cambrian rocks, which had been to a great extent, if not wholly, buried by sediments of the Silurian sea during its eastward migration. But now in consequence of erosion corresponding

[1] Several articles in the Journal of Geology, Chicago, summed up in An Hypothesis of Cause of Glacial Periods, Journal of Geology, Vol. VII, No. 6, pp. 563-568. Sept.-Oct., 1899.

to the accumulation of the lower Silurian shale formations, areas of the pre-Cambrian rocks were laid bare in the higher lands of Appalachia east of the coastal plain. Several conditions combined effectively to decompose and oxidize them. They had already in Cambrian time been superficially disintegrated and probably not eroded down to perfectly fresh rock during the transgression of the shore. While buried under sedimentary beds, the rocks beneath the plane of unconformity were subject to the action of waters which found along that plane an easy course of percolation. Thus, when uncovered, the ferriferous minerals were prepared for dissolution. But more effective conditions followed from uplift and consequent erosion. Valleys being cut in the elevated mass, the level of standing ground-water was lowered and a corresponding volume of rock was affected by atmospheric waters percolating downward. Such waters carry carbonic acid which dissolves, and oxygen which oxidizes many mineral constituents, and among them iron. The process of weathering proceeded more rapidly than that of denudation, and so long as that relation of activities continued the land was deeply mantled with soil and decayed rock, furnishing abundant iron oxide to the sediments removed by streams.

As a supplement to the preceding explanation, a further hypothesis may be stated. It is believed that the deposition of a stratum of limestone is accompanied by the liberation of carbonic acid, which, having been combined with lime as bicarbonate in solution, is set free in the ocean and passes into the atmosphere, while the lime takes the relatively unsoluble form of monocarbonate. When the limestone deposit is extensive and thick, as the Cambrian-Silurian limestone was, the small proportion of carbonic acid in the atmosphere may be notably increased, as has been pointed out by Chamberlin.[1] By this action the atmosphere in mid-Silurian time was probably enriched in carbonic acid, and the rains which fell contained an important proportion of that active solvent. Thus the decomposition of ferriferous minerals proceeded with peculiar energy.

[1] Chamberlin, "The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere," Journal of Geology, Vol. VI, No. 6, pp. 609-621.

VIEW OF THE WESTERN SLOPE OF WILLS MOUNTAIN IN WILLS VALLEY, NEAR CUMBERLAND.

Two activities appear to have shared in depositing the iron thus provided by rapid disintegration of ferriferous rocks. That part of the iron which was oxidized in the rocks before denudation exposed it, when eroded, became a fine sediment intimately associated with clay, and as such was readily swept to the sea in muddy rivers. Its fineness sufficed to promote a separation from the coarser sands of quartz and undecomposed minerals. Another part of the iron, which was dissolved by carbonic acid and not oxidized in the mass of decomposing rock, entered the underground water circulation and through springs and streams flowed to the sea. It may have been oxidized in part *en route* or in part in the sea, whose surface in play barters with air.

The waters of the gulf on the west had become shallow near the shore as the trough was filled with shale, and perhaps as the general relative uplift of Appalachia spread westward. The deposits were not stirred or sorted by the slight wave action of the shallow water, and the coarser particles remained coated with the fine ferruginous mud.

The white sandstone (in these reports called the Tuscarora) which follows sharply upon the clayey red shale and sandstone differs from them in being thoroughly washed and freed from fine sediment. It is a characteristic deposit of a wave-beaten beach, cleaned and spread by transient currents, frequently with cross-bedding. The ripples which distributed the red muds of the preceding strata were the spent vanguard of waves which broke on the distant margin of the shallows. Slight deepening of the water along that margin, or gentle tilting of the bottom westward, may have sufficed to permit the zone of breakers to advance eastward. In advancing they stirred the surface of the red deposits and redistributed the materials; they built barrier beaches and scoured the sands upon them; and the undertow swept even quite coarse detritus down the slope toward deeper water. As this activity progressed beyond the area of red muds and attacked possibly earlier coastal plain strata and the coarse detritus remaining from the residual mantle, it reached a large volume of quartzose material. The thickness of the white sandstone, 600 to 800 feet, indi-

cates that the source of supply was large, and its coarseness even as far west as Wills Mountain near Cumberland shows that the waves repeatedly swept back and forth over the submarine coastal terrace. The slope of that terrace may be compared with that of the present Atlantic shelf of North America, which descends from the shore seaward at the rate of about 6 feet per mile for 100 miles, and then sinks at the rate of 300 to 700 feet per mile 10,000 feet into the oceanic abyss. The slope on which the white Silurian sands were washed was probably more than 6 feet per mile, but much nearer to that figure than to 300 feet. The massive white sandstone thus formed, which gives to the Narrows in Wills Mountain their picturesque cliffs, is a remnant of the ancient Silurian coastal plain. After millions of years of burial, the sands are again entering the circulation by river and wave to become part of some beach and to record the passing aspect of the Atlantic shore.

THE APPALACHIAN GULF CLOSED AT THE NORTH.

The coastal plain strata which have been described constitute in New York the Oneida and Medina formations, which extend west of the Hudson and south of the Mohawk rivers in such manner as to define approximately the northeastern limit of the Appalachian Gulf at that time. Communication with the St. Lawrence depression was apparently barred by a rising land area and the gulf became a long water body open only at the southern end.

The uplift which thus closed the northeastern outlet of the sea has been described[1] as a mountain-making disturbance, which produced the Taconic mountain range. The elevation which now constitutes that range is of later date than the Paleozoic era itself, as has been shown by studies of the physiography of New England,[2] and the mountain-making of Silurian time can only be judged by the disturbances of the rocks and the volume of resulting sediments. The disturbances of which the Silurian rocks now exhibit the effects were intense and were probably not accomplished in a single episode.

[1] Manual of Geology, J. D. Dana, 4th Edition, p. 527.

[2] The Physical Geography of New England, Wm. M. Davis, p. 269 et seq. in Physiography of the United States, Am. Book Co., 1896.

The date or dates of their occurrence are Silurian or later. The more effective movements may have been Carboniferous. In certain localities there is, however, a discordance between the attitude of earlier Silurian strata and those of the coastal plain episode which has just been described, and the earlier sediments had evidently been disturbed. A distinct elevation of New England and adjacent areas is indicated in the deposits of the Oneida, Medina and Clinton epochs, but it would appear that the uplift was not of conspicuous mountainous height as the volume of sediments contributed to the Appalachian Gulf from erosion of the area was moderate.

Shallow Waters and Lowlands; Upper Silurian and Early Devonian.

OSCILLATIONS OF RELIEF OF LAND AND DEPTH OF WATER.

Conditions of climate and rock-exposure continued to be favorable to the erosion of clayey and ferruginous sediments, as they had been before the white sandstone was spread. The waters of which it had become the bottom were shallow and swept by tidal currents, which may probably have been strong in the restricted gulf. The bottom was slowly subsiding, while strata were rapidly accumulating, and the depth of water changed from time to time. Gray and red and olive-green shales and sandstones, which vary greatly in color and texture from layer to layer and place to place, record the conditions. They attain a maximum thickness of 2,600 feet in Pennsylvania, and elsewhere are 1,000 feet or more thick. Occasional calcareous beds, especially rich in iron and known as the Clinton iron-ores, mark episodes of peculiar conditions whose character, widespread occurrence and recurrence at intervals have not been explained. Although oxidized at the present outcrop the iron in unweathered beds occurs as carbonate. The deposits are therefore of a chemical nature.

The very moderate oscillations of relative level of land and sea, which sufficed to contribute and distribute the sediments of Silurian time, had not involved any conspicuous mountain growth. Whatever hills may have diversified the Silurian landscape of Appalachia were carved by rain and streams from broad low uplifts. The plains

that now stretch from the Mississippi to the Rocky Mountain Front may present a similar relief, especially where vegetation is absent, as in the Bad Lands. In contributing the waste which forms the Clinton sequence, Appalachia had again sunk to a low featureless plain. Consequently when the gulf deepened over Ohio and western New York, little or no sediment clouded its waters, in whose clearness corals flourished and, with other invertebrate organisms, built up the Niagara limestone.

During the succeeding episode the waters of the gulf along its northeastern and northern shores again became shallow, so that calcareous muds accumulated. The corresponding tide-flats repeatedly afforded conditions for evaporation of sea-water from extensive pools, in which salt crystallized in beds of considerable thickness. Again deepening, the waters permitted the accumulation of the calcareous sediments which form the Helderberg limestone.

As the Appalachian Valley from New York southward and the zone extending a hundred miles to the west, was the belt over which the shore of the gulf fluctuated during the upper Silurian, the record of that time was there made in detail, and the broader aspects may be lost in following the minor episodes. But the white mark which the waves built at the beginning of the upper Silurian, the Tuscarora sandstone, was in a measure duplicated by them in the transition to the next succeeding period, the Devonian. The second mark is the Oriskany sandstone.

The Oriskany is composed of clean quartz grains and pebbles in a calcareous cement; locally it is limestone, and elsewhere it is quite purely quartzose. Like the Tuscarora sands, those of the Oriskany had been wave-beaten and sorted on the coast during preceding epochs, where they were stored in the zone of beach development so long as the seaward slope was nearly level. When that slope grew steeper, as their distribution demonstrates, they were swept out into the area where calcareous deposits were still accumulating.

The Tuscarora sands were spread beneath a sea which was pushing its shore eastward across broad tide-flats. The Oriskany sands, on the contrary, were deposited west of a shore which was proceeding

westward. The waves which delivered them to the sea passed westward over the resulting stratum, which was added to the land. It was exposed at a very low level and gentle slope, but it is generally more or less eroded on its upper surface.

The continent of Appalachia has thus far been discussed as a whole without division into northern and southern provinces, but the strata are not strictly uniform along the entire coast from New York to Alabama, and the detailed interpretation would vary if written for Georgia from that which would be logical for Maryland. The episodes of oscillation of sea-level, which permitted the spreading of upper Silurian sediments succeeding those of the Clinton formation, did not extend to eastern Tennessee and Georgia. After the earlier events of the upper Silurian, which developed the ferruginous Rockwood formation of the South, the shore stretched through central Tennessee and thence westward. The region to the east and south was a lowland. During the Oriskany epoch, brownish sandstones were washed over its margin as far east as northern Georgia, but the subsequent gentle elevation of Appalachia sufficed to expose the stratum to erosion, and much of it was removed.

The student of physical changes finds no important episode of mountain growth or continental development to define the close of the Silurian period and the beginning of the Devonian. The record describes Appalachia as a monotonous lowland now rising a little higher, now not so high, above the fluctuating coast of marsh and beach and tide-flat. But the evolution of organisms ran its course and extinction and migration repeatedly changed the population of the Appalachian sea. Before the Oriskany epoch it had assumed those aspects which are considered to characterize the Devonian period.

THE WIDE EXTENT OF THE DEVONIAN LOWLAND.

During the episode of erosion of the low-lying surface of the Oriskany sandstone, the adjacent gulf on the west and northwest supported a rich fauna of corals which built up a limestone known as the Corniferous. In significance as to physical conditions it is sim-

ilar to the Niagara limestone, the waters having been clear and warm, a congenial habitat for coralline growths. The absence of mechanical sediment bears testimony to the fact that the waste of the low plains of Appalachia was being stored in broad marshes along shore, where aquatic vegetation may have aided to filter the currents flowing seaward.

Succeeding the Corniferous limestone and overlapping upon the eroded surface of the Oriskany eastward as far as the central line of the great Appalachian Valley is the black shale, in these reports called the Romney formation, and generally known as the Hamilton group. It is a fine-grained, calcareous or sandy mud-rock, black or dark brown with organic matter, and often bituminous. In Alabama it is but a few feet thick and thins out to a feather edge to the south and east; in Maryland it attains a thickness of 1,400-1,500 feet, and thence grows thinner toward its northern outcrops in New York, where the thickness is about 1,200 feet.

Only the great Cambrian-Silurian limestone exceeds this bed of black shale in uniformity and extent of occurrence. Its distribution corresponds to an eastward and southeastward migration of the coast from the shore of the Corniferous gulf over the low marshes of Appalachia. The submergence brought within range of the waves quantities of vegetation and the sediment of estuaries, while the warm shallows afforded a habitat for algæ and a fauna that found the muddy waters congenial. The duration of the epoch is not to be measured by the thickness of its sediments; not only do they vary from 15 feet or less to 1,500 feet, but the thin layer of black shale in Alabama and Georgia appears to be all that accumulated in that region until after succeeding Devonian strata in Pennsylvania had attained a total thickness of 10,000 feet. There is perhaps nowhere a more striking illustration of the intimate relation between the rate of sedimentary accumulation and the topographic phase of the adjacent land. The thin stratum of black mud which, during a long epoch gathered in shallow waters, without material addition of other sediments or removal of its own insignificant layer, demonstrates the stability of a sea-level plain. Time passed unrecorded there. Ten

LEGEND

Ds

within which Devonian sedi-
now outcrop and which was
ngly submerged during a part
whole of the Devonian period.

Ds ?

probably submerged in whole
art.

Ld

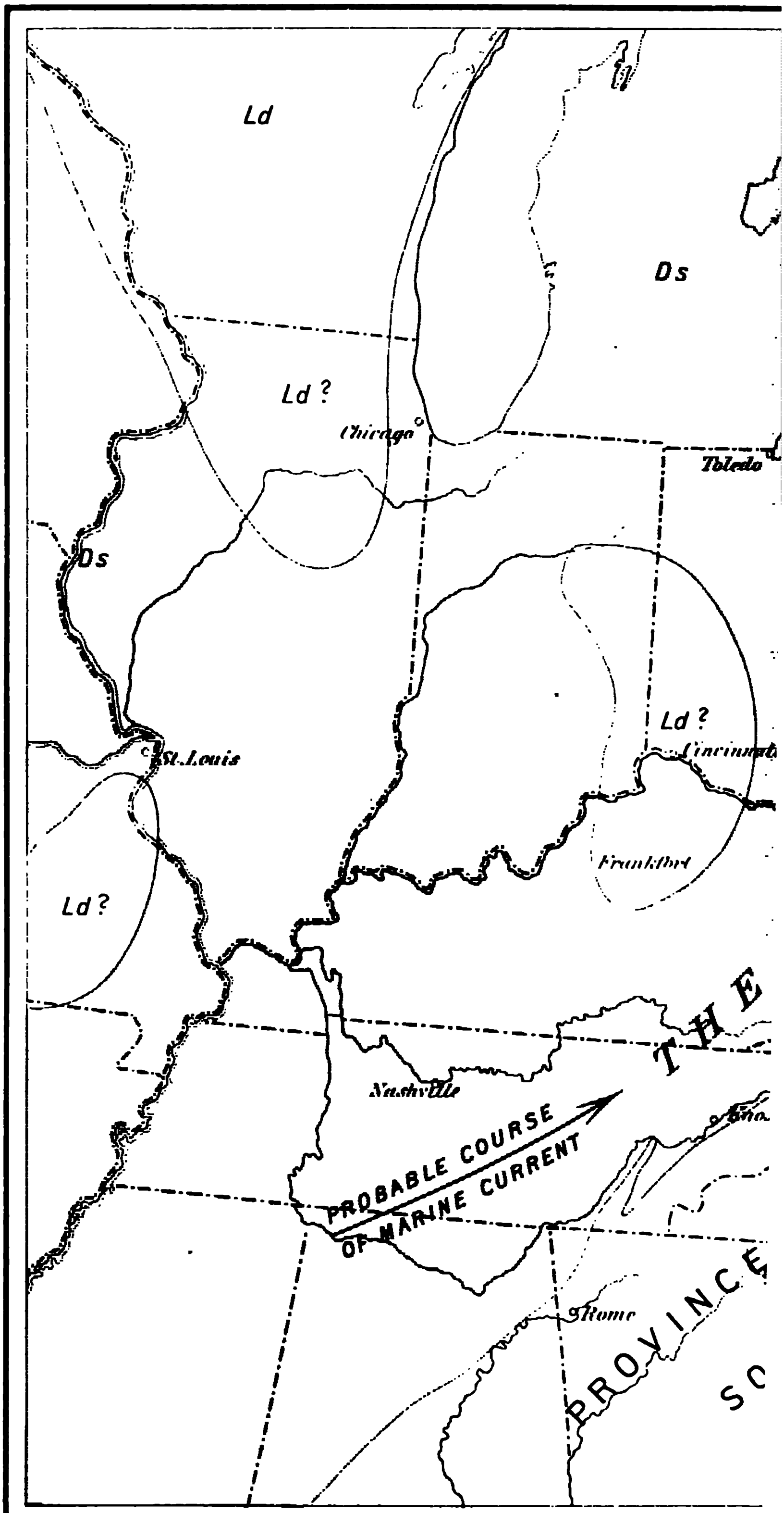
areas existing toward the close
Devonian period.

Ld ?

areas which may have existed
part of the Devonian period.

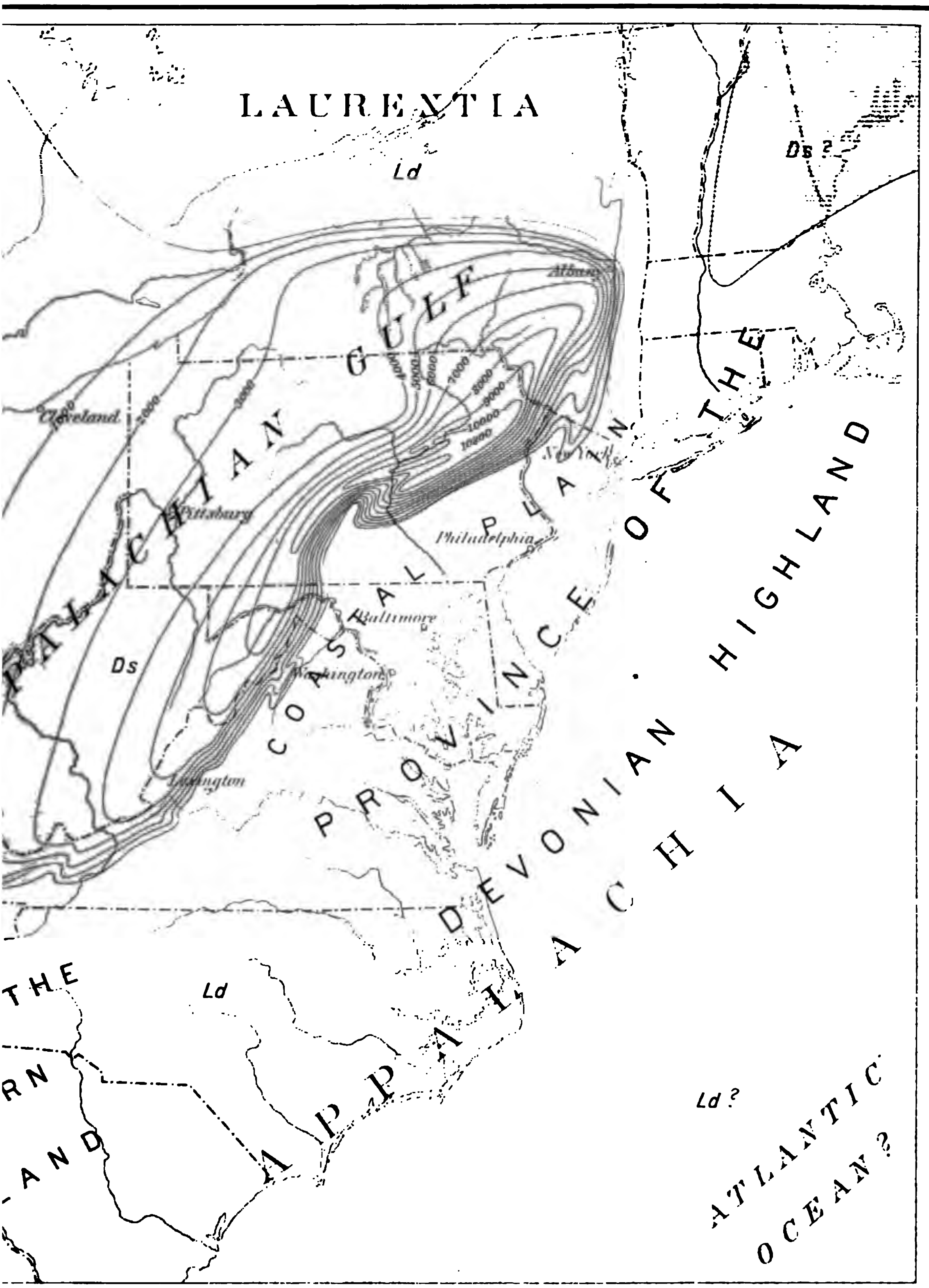
3000

contour lines represent the ap-
ate form of the black shale for-
after development of the basin
the succeeding Devonian sedi-
athered.



Based on Map of
Devonian shorelines
H. S. Williams 1896.

Geog



the Eastern United States
nd at the close of the
evonian Period

Bailey Willis
1899

A Hoen & Co. Lith. Baltimore

thousand feet of sediment, during the same epoch accumulating in the neighboring sea, represent a transient height of land and rivers flowing from it. Thereby events were voluminously recorded.

The general distribution of the black muds of the Hamilton was the last episode of the series of gentle oscillations of sea-level which had varied the sequence of events during all later Silurian and earlier Devonian time. The monotony of the movement was then interrupted.

The Devonian Highlands.

CHARACTER AND VOLUME OF SEDIMENTS.

Succeeding the black Hamilton shales from New York to southern Virginia occurs a great volume of sandy shale and argillaceous sandstone comprising the Jennings and Hampshire formations of Maryland or the Chemung and Catskill of New York. It is divisible into several formations according to the composition, color, texture and included fauna of successive beds, but it is a unit in so far as it represents physical conditions of land and sea which were favorable to rapid erosion and deposition. The strata are thin, rapidly alternating in character, current-bedded, and ripple-marked. They vary in color from buff or gray through shades of green and olive to dark purple or deep red tints. Their constituents are clay, fine and coarse sand, occasional quartz pebbles, and in some strata abundant scales of mica. Oxide of iron is an important constituent, especially of the higher beds to which it gives their preponderantly red color.

The thickness of the mass varies in such manner that the deposit has somewhat the form of the internal cast of a great mussel shell. The thin edge of the cast extends from Lake Erie southward through Ohio and eastern Kentucky to eastern Tennessee, where one end of the mass is. Thence the hinge-line of the mussel-shaped form runs northeast to New York, whence the thin edge rounds westward. The upper surface of this cast may be considered to be flat and the under surface curved to the hollow of the shell, which is deepest along the hinge-line. The dimensions of this form are: Width from Washington county, Maryland, to northwestern Ohio, 300 miles;

length from northeastern Tennessee to Albany, New York, 700 miles; the greatest thickness in Schuylkill county, Pennsylvania, over 10,000 feet. The area covered by it exceeds 100,000 square miles. If this mass, with approximately the dimensions with which it was deposited in the sea, could be restored upon a sea-level plain of Appalachia, it would constitute a mountain range closely resembling in height, extent and mass the Sierra Nevada of California. Its position, with reference to the ancient coast, would also be similar to that of the modern mountain range with reference to the Pacific. These sediments are the waste of a Devonian highland which grew and suffered erosion during that period.

TOPOGRAPHY OF THE HIGHLANDS.

The preceding comparison may serve to give a crude estimate of the magnitude of the Devonian mountains, but it does not follow that the ancient range resembled the Sierra in topographic character. If the former rose more slowly than the latter it may always have been of gentler aspect and never so elevated. Their nearest genetic likeness lies in the fact that both ranges developed where previously a plain extended.

The topography of the Devonian highlands can be conjectured only from the character of the sediments. Their constituents are all the product of thorough chemical decomposition of siliceous crystalline rocks; they are coarse of grain and unassorted. Particles, light and heavy, coarse and fine, are intimately mingled. The general disintegration of the original rocks to the texture of sand and clay indicates deep accumulation of soil, as in the Appalachian Mountains of the present day where weathering of the crystalline rocks very generally proceeds faster than the removal of the products of rock-decay. The dark red color of many strata is due to oxidation of iron from deeply decayed ferriferous rocks. The Devonian highlands probably exhibited rounded forms of hill and valley, and thus may be contrasted with those ranges which present savage precipitous profiles. The presence of mica and of heavy minerals not easily decomposed indicates that the sediment was derived directly from

the decaying rocks; it had not been stored in flood-plains, coastal plains, or estuaries during previous ages. Its immense volume suggests large streams whose turbid floods coursed swiftly to the sea.

The unassorted mingling of sandy and clayey particles is a result of rapid deposition at the mouths of muddy streams in opposition to waves which are too weak to sort and distribute the volume of sediment. This is a condition of delta-building. In the Devonian sediments as they are now exposed to view the typical contour or profile of any delta may not be observable, but the stratification is not less significant. The frequent and irregular interbedding of coarse sands, sandy clays and clays; the cross-stratified beds, the ripple-marked and sun-cracked mud surfaces, the channels scoured by transient streams, all prove the abundance of the sediments, the shifting conditions of deposition, the irregularity of currents, the wide expanses of tide-flats and shallow waters, and the weakness of the waves.

THE CHARACTER OF DEVONIAN DEFORMATION.

Shallow waters prevailed over an area several hundred miles in extent along the coast and one hundred to one hundred and fifty miles wide from the shore westward; and during the accumulation of from 6,000 to 10,000 feet of strata the upper surface of the deposit was repeatedly just at sea-level. These facts are inconsistent with stability of the sea-bottom. The water was now deeper, then shallower; it withdrew, and as often returned over many square miles of flats. The floods and low waters of tributary rivers and the ebb and flood of tides, together with the gathering sediment, may be considered adequate to explain many minor variations, but the range of these oscillations across a hundred miles or more is evidence of those crustal movements which cause changes of the sea-level. These movements were very slight in vertical amount, but very frequent; and the sum of downward movements was greatly in excess of those upward, so that the total result was a deep subsidence. Since the surface of the sediments accumulated in the depression was repeatedly near sea-level, the deposits obviously filled the basin as it developed, but the completeness of filling was intermittent, the

water being now deeper, now shallower, as the rates of sedimentation and vertical oscillation of the shore zone varied relatively.

Before the deposition of these later Devonian sediments, the sea-bottom on which the black muds were spread presented a gentle, even slope westward, and the adjacent plain of Appalachia extended that slope eastward. During the deposition of the succeeding Devonian sediments, the submarine plain was tilted down eastward, so that it descended from Ohio to Maryland 10,000 feet in 300 miles. The terrestrial plain, on the other hand, at a long distance from the sea, was elevated several thousand feet and given a westward inclination. Thus a depression and an uplift were simultaneously developed in opposition one to the other, probably with a wide coastal plain between, and the hollow was filled by the highland, the material being transferred by that activity of erosion and sedimentation which followed the movements. The original cause of those movements and the conditions controlling them form interesting subjects for speculation.

CLOSE OF THE DEVONIAN PERIOD.

Again the student of Appalachian physical changes finds the end of the great period paleontologically marked at an epoch which is part of an apparently continuous sequence of events. There is no evidence of an interruption in the sedimentary record which might correspond to an hiatus, nor of any continental or provincial catastrophe to close the Devonian or open the Carboniferous chapter. But in all probability the change in organisms marks a lapse of time which was long in proportion to the thickness of strata deposited toward the close of the Devonian.

It has been stated that in Georgia and Alabama Devonian strata are very thin, and the fact has been explained as a consequence of the very slight elevation of the adjacent land. When the northeastern Devonian uplift had culminated and the rate of erosion exceeded that of elevation, the highland entered upon the later stages of mature topography marked by minutely branching valleys and ridges, and progressed toward the aspect of an aged landscape, a lowland. The episode of maximum waste is that of maturity, and

during the succeeding stages of topographic development the detritus removed grows constantly less and less until it almost fails. The rate of accumulation of sediments decreases correspondingly. Thus the latest Devonian strata may probably represent much longer time than those deposited during the maximum development of the highlands. The result of the activity of erosion was the expansion of a generally low but not featureless landscape on the site of the Devonian highlands.

Appalachia During the Early Carboniferous.

SOURCE OF THE POCONO SANDS.

The shallowness of the Devonian sea has been emphasized in the preceding paragraphs, because it is one of the most striking and significant facts of the corresponding episodes. But from time to time waters prevailed of such depths that waves played energetically along the shore of Appalachia, and accomplished the sorting of a large volume of material. The muds sorted out were added to the greater mass of river sediments; the clean sands and pebbles were left on the broad coastal plain of Appalachia over which the waves migrated. In general, during the transgressions of the sea, the place of deposit of the sands was inland, beyond the mouths of estuaries and the belt of tide-flats which were bared during recessions, but the slope of the off-shore plain was too low for the distribution of coarser detritus. Here and there through the Devonian muds occur limited lenses of peculiarly coarse sandstone or conglomerate, the fringes of the extensive coastal plain formations spread far to the east.

When, after the close of Devonian time, the continental landscape had taken on the monotony of an undulating plain, there occurred a slight submergence accompanied by tilting of the plain toward the west. Rolling across the slowly deepening waters, waves broke on the coastal plain, stirred the incoherent sands, and delivered to the undertow all that was not too coarse. Swept out and mingled with shore drift of plants and with more or less mud from the inactive rivers, the sands and pebbles formed a bed of sandstone and conglomerate generally known as the Pocono sandstone.

Along the eastern outcrop in Maryland, Pennsylvania and New York, the Pocono sandstone varies from 400 to 2,100 feet in thickness. Westward it thins rapidly, and, by interbedding with red and gray muddy deposits, passes into shales in Ohio. Southwestward it underlies and thins out beneath the limestone, which represents the early Carboniferous deposits of the widely extended interior sea of the West.

THE EARLY CARBONIFEROUS LOWLANDS.

The Carboniferous limestone, like the great Cambrian-Silurian limestone, is a formation which was related to a general condition prevailing over the surrounding lands. Of great thickness and massiveness in the Rocky Mountains, the Central States, and the southern district of the Appalachian province, it records the general development of low-lying plains. But northeastern Appalachia, though low along the shore during the Pocono episode, continued to contribute much sediment from the hills of the interior, and rising gradually for a time, renewed in a moderate degree the conditions which existed during the uplift of the Devonian highlands.

THE EARLY CARBONIFEROUS HIGHLANDS.

Where not covered by the limestone, the Pocono sandstone is succeeded by red and greenish sandy shales known as the Mauch Chunk formation. The beds are ripple-marked and current-bedded throughout. Their thickness is greatest along the eastern side of the Southern Anthracite field, where it exceeds 2,000 feet. The red shales thin westward and southwestward and grade into corresponding beds of limestone. Thus it appears that the Mauch Chunk, like the great red formation of the Devonian, is a deposit limited to the northeastern portion of the Appalachian gulf, and that it represents a height of land which was elevated, eroded, and distributed in the Carboniferous sea. Elsewhere the bordering lands about that sea were low, and mechanical sediment failed, while calcareous sediment, largely and perhaps wholly of organic origin, accumulated.

The strata corresponding to this highland are not as voluminous as those which represent the Devonian mountains, and it may be inferred that the uplift was correspondingly smaller. The movement

was, however, identical in character; the trough which contained the Devonian sediments gradually deepened more than 2,000 feet and was continuously filled by the Mauch Chunk strata. The eastern land was elevated sufficiently to rejuvenate the rivers which reassumed the character of vigorous turbid streams.

Development of the Carboniferous Coastal Plain.

NATURE OF THE SEDIMENTS.

The later episodes of the Carboniferous period, during which the coal deposits accumulated and the Appalachian gulf was filled, comprised a very complex sequence of events. The effects were not uniform throughout the province. The strata are irregular and the succession varies greatly from place to place. It is not possible in this brief account to discuss any section in detail, but only to give an explanation of general conditions, which may correspond fairly well with the facts.

Quartz is the predominant constituent of the strata. As pebbles and in coarse or fine grains it constitutes nearly the whole of many conglomerate and sandstone beds, and it often forms the greater part of strata, whose fine texture causes them to be classed as shale or clay-rock. In so far as they are not quartzose, the strata are of clay. Iron occurs as an incidental constituent in small proportion throughout the series and as carbonate in thin beds, but the red color so conspicuous in the preceding Devonian and Mauch Chunk strata is wanting. Decomposed granitic minerals, such as feldspar, occur in small proportion in sandstones. The coal beds are fossil vegetation. They consist chiefly of carbon derived by the agency of plants from carbonic acid of the atmosphere, and stored as carbon and as hydrocarbons. The plants grew luxuriantly in extensive marshes.

In the proportion of quartz they contain many of the conglomerates and sandstones resemble the Tuscarora, the Oriskany, and the Pocono Coastal Plain formations, but in coarseness the conglomerates, especially the lowest or Pottsville conglomerates, greatly exceed any previous deposit.

The beds are generally cross-stratified, irregularly bedded as by swift and transient currents, interbedded with marsh deposits, locally

eroded, or overlapped, an earlier by a later group of strata. These are evidences of repeated variations in depth of water and of the activity of waves and strong currents along shifting shores.

The thickness of strata above the Mauch Chunk shale varies from 2,000 to 4,000 feet along the eastern outcrop, and the equivalent series above the limestone toward the west and south thins to 1,000 feet or less. In the Appalachian gulf east of the Cincinnati uplift, the strata cover approximately 80,000 square miles. The volume of sand and clay is not equivalent to a high mountain mass over the same area of Appalachia. But although the volume of sediments as it was deposited is not large as compared with a mountain range, the mass of rock from which it was derived was of great magnitude. Quartz, the predominant constituent of these Carboniferous strata, is a comparatively small component part in a free state of the pre-Cambrian schists and granites, yet it was no doubt produced by their decomposition and by the disintegration of the quartz veins by which they are cut. The proportion of free quartz in the old rocks is not definitely known, but if it be assumed to be as much as one-third, a highland which should supply the Carboniferous sandstones from a base of 80,000 square miles, should rise to a crest of 6,000 to 12,000 feet. Had such a highland existed in Carboniferous time, the deposits resulting directly from its destruction should include not only the quartzose, but also the more voluminous clayey formations. That the quartz only is represented may be explained by prolonged storage and concentration of that durable mineral in a coastal plain as was stated on page 52. In that event the clayey deposits corresponding to this volume of quartz should be looked for in earlier formations of the Carboniferous or even of the Devonian period. The clay was then widely distributed, perhaps far from the shore where the quartz sands and pebbles were being washed and rewashed, until they, too, were buried in strata.

WESTWARD TRANSFER OF THE COASTAL PLAIN.

The Pottsville conglomerate, which succeeds the Mauch Chunk shale, is a remarkably coarse deposit. Quartz pebbles 1 to 3 inches

in diameter constitute thick strata along the southeastern outcrops in Pennsylvania and much larger pebbles occur. Fifty to one hundred miles farther west the formation is represented by pebble beds, in which the pebbles may attain a diameter of an inch, and by coarse sands. These coarse, clean quartzose deposits lie immediately upon the muds of the Mauch Chunk formation, and thin layers of the mud are sharply interstratified with the lower conglomerate and sandstone beds. The marked contrast in the sediments is significant of a change in depth and slope of the sea-bottom. Tide-flats of the Mauch Chunk epoch were submerged, and their practically level surface was in part replaced by one having a decided seaward inclination.

These conditions of deposition of the coarse Pottsville sediments may reasonably be stated as follows: Gentle subsidence of the sea-bottom sufficed to establish a moderate depth of water over a wide area previously shallow. As the conditions became favorable for them, strong currents circulated. They washed the surface of the Mauch Chunk deposits, scouring off the unconsolidated mud and filling depressions. They checked the development of deltas by sweeping the river mud away to greater depths. Rising relatively to the coastal plain, the sea flooded low valleys, producing estuaries. Between these stretched low peninsulas composed in part, at least, of coarse and fine quartzose coastal plain deposits. Waves, favored by the depth of water, attacked the headlands, and cutting across their ends, built out spits of gravel and sand, which they extended across the mouths of estuaries. Here waves and littoral currents, both most effective during great storms, contended against the rivers, which carried most sediment during occasional floods, and here accordingly the quartzose coarse deposits of the former alternated irregularly with the muddy strata spread by the latter. The wave-built features along the coast assumed the profile of shore terraces, sloping from the beach gently or steeply, according to the grain of the material and the strength of the action, as far out as the waves could agitate and roll the detritus, and thence more steeply into the deeper water.

The width of terraces which may be built by waves at a constant relation to sea-level is narrowly limited by the character of the material and the strength of the waves; but along a shore washed by strong currents there is a reaction between the embankment and the current as a result of which the deposit is extended. As the terrace is built out it encroaches upon the course of the current which becomes accelerated by being confined. The encroachment may continue until the acceleration is sufficient to enable the current to scour the face and so prevent further widening. Whatever material, within the transporting power of the current, the waves thereafter deliver across the terrace is carried along shore and deposited as the current slackens in deeper water. This process is continuous so long as the supply of sand holds out, and the activity of a current may thus result in depositing abreast of any section of the coast a great volume of shore drift derived from an adjacent section. Thus result material differences in thickness of deposits along a coast.

During progressive subsidence of the sea-bottom the supply of detritus from the coastal plain of Appalachia was continued. The downward movement may have been to a certain extent shared by the coastal plain; then the shore and its attendant terrace advanced eastward and the shore currents scoured the surface of each previously wave-built structure, redistributing the sands and gravels of which these were composed. During the greater part of the subsidence, however, the movement was probably not shared by the coastal plain of Appalachia. The maximum thickness of the Pottsville formation in eastern Pennsylvania is 1,200 feet, and the surface of the Mauch Chunk subsided to that extent during the Pottsville epoch. Had the coastal plain been equally depressed the sea would have transgressed far to the eastward and the accumulation of coarse detritus would not have been concentrated to so great a thickness in a narrow zone. The Appalachian plain was probably raised and tilted westward, delivering the coarse and fine land-waste to a shore which did not migrate far east of a certain limit.

The gathering of a great thickness of gravel and sand in a narrow zone in the presence of waves and currents was accompanied by a

corresponding widening of the deposit on the sea-bottom. To estimate the width which the deposit might attain during a simple episode of submergence, reference may again be made to the submarine slopes on the Atlantic shelf. Off the south shore of Long Island the sandy bottom descends 45 to 60 feet in the first mile from the beach, and for 5 miles out at the rate of only 15 to 20 feet per mile. Off Cape Hatteras, east of the outer Diamond Shoal, the bank which lies 15 to 20 fathoms below the water has a greatest slope of 30 feet in one-quarter of a mile, or 120 feet to the mile. The materials of this bank are pebbles and broken shell. If the slope of the Pottsville formation was constructed under similar conditions, the width of the base on a level west of the zone of maximum thickness would not have exceeded twenty miles. In fact, the extent of the coarse pebbly strata west of the maximum thickness considerably exceeds a hundred miles. Unless improbable assumptions as to the strength of currents be made, it is apparent from the above comparison that a simple episode of submergence is not adequate to afford the conditions essential to spreading so widely this conglomeritic formation.

The Pottsville formation affords much other evidence of the complexity of conditions attending its development. For example, among the variable strata of which its mass is composed, are coal beds. Some of these are of driftwood buried in current-bedded sand, but others are evenly laid marsh or lagoon accumulations, and though thin, they record an episode when some portion of the sands had temporarily emerged from the sea. The growth of vegetation which formed the coal took place after the surface had passed from submarine to land condition, that is, after the line of breaking waves had retreated across it. During such retreat the shore lay along the generally uniform slope of the latest stratum of sand and gravel, which was thus subjected to wave erosion. The efficiency of the waves depended upon the depth near shore and that of the transporting currents upon the relative steepness of the slope. The deeper the water inshore, the steeper the immediate slope away from the shore; and, accordingly, the more efficient the waves in eroding the

beach, the more favorable the conditions of transportation. By this activity coarse sediments may probably have been swept over a wider expanse than that on which they might accumulate during a simple submergence. The movements did not necessarily include an episode favorable to accumulation of coaly material, but may have occurred with scarcely perceptible evidence of rising and sinking, yet it is by repetitions of submergence and emergence, probably, that the gravel and sand delivered from the coastal plain of Appalachia formed the very extensive Pottsville deposits.

The above described process of distribution of coarse detritus over a wide area involves the migration of a relatively steep facet in the slope of the coastal plain and submarine shelf. This facet must migrate in a plane constantly near sea-level, and be limited above by the widening or narrowing gentler slope of the coastal plain, and bounded below by the even more gradual incline of the relatively narrowing or widening submarine shelf. These limiting conditions are suggested on the one hand by the inactivity of atmospheric erosion, which remains relatively unimportant during the migrations, and, on the other hand, by the efficiency of scouring currents which, on passing into deeper water, would fail to move coarse material. The amount of vertical movement during any single episode of submergence or emergence is very slight. The maximum depth of water indicated by the effectiveness of currents is probably less than 100 feet, and the elevation of the coastal plain, which is consistent with ineffective erosion and the accumulation of marsh mud, is practically nil.

LAGOON AND MARSH DEPOSITS.

The Pottsville formation consists in large part of coarse deposits, but by no means exclusively. Throughout the New River district of West Virginia and further to the west and south, it contains much fine sandstone and shale with several important coal beds, and thus resembles the productive coal measures which, in the central Appalachian coal fields, formed during succeeding epochs. In strong contrast to the sandstones and conglomerates—deposits of swift-moving waves or currents—are coal beds which accumulated in the

quiet of marshes and lagoons. And scarcely less anomalous appears the intimate interbedding of fine shale, containing numerous remains of land plants and apparently deposited in fresh water, with the coarser sediments. Still another characteristic of the Pottsville, and of succeeding Carboniferous formations in general, is the lenticular form of many deposits, in consequence of which any one bed of sandstone, shale, or coal thins out and is replaced in its own horizon by a deposit of different texture. The significance of these peculiar relations is that the bottom of the open waters and the surface of the land were very near the same level, the waters being shallow and the lands being very low, as has already been stated. And, further, the barriers dividing the sea from the lagoons and swamps of the lowlands were sinuous and shifting. They were barrier-beaches built by shore currents and waves across shallows, or mudbanks accumulated at the mouths of streams, or even nothing more than marginal thickets of rank tropical plants, differing in flora but similar in density to those which now fringe the coasts of Central and South America along the Caribbean. The interior sea shallowed till it became in great part a tropical swamp, composed of irregular morasses, lakes and estuaries. These features were modified at intervals by river floods. Again the surface was more deeply submerged in consequence of slight subsidence, and swift currents of estuaries or marine waters swept in coarse quartzose sediments.

LATER CARBONIFEROUS CONDITIONS.

The deposition of the Pottsville formation was succeeded by many varied sediments which gathered in the Gulf of Appalachia during the later epochs of the Carboniferous era. Some of the strata are sandstones resembling the Pottsville and record an abundant source of quartzose sands and the appropriate conditions of distribution. Other strata are of shale or coal. They are generally of lagoon and marsh origin in the eastern and southern part of the basin, but toward the west and northwest extensive and regular deposits of shale and numerous layers of impure limestone indicate that marine conditions returned frequently in alternation with those of the low coastal flats.

In the marine area the movements were gentle vertical oscillations, according to which the sea-bottom now emerged to just above sea-level and again subsided to depths of 100 feet or more. As sediments accumulated to thicknesses of several thousand feet upon the Mauch Chunk shale, the sum of subsidences was, on the whole, that much greater than the sum of emergences. According to the thickness of sediments, the gross subsidence was also much greater in the eastern part of the sea, along the coast of Appalachia, than it was in the region corresponding to the Mississippi Valley.

During these oscillations of the sea-bottom, the Appalachian land rose slowly and probably intermittently, and not to any great height. The Carboniferous strata record no such mountain range as that which grew in Devonian time, yet the total Carboniferous rise of Appalachia was probably equivalent to a highland of 1,000 to 3,000 feet, and would have resulted in sediments significant of decided elevation had the uplift proceeded more energetically.

In general the gentle movements of land and sea-bottom determined corresponding activities of erosion and sedimentation, such that the broad coastal plain of Appalachia migrated from the zone it had occupied during Devonian time far to the west. Where the shore stood during any particular episode is a question of detailed evidence which may sometimes fail to be conclusive, but there is no doubt that it passed from a position in eastern Pennsylvania and central Maryland and Virginia westward to the Mississippi Valley.

At the end of the activity the Gulf of Appalachia was filled. No further general subsidence of its basin occurred, and the accumulation of marine sediments in that region ceased. Therewith the record of Paleozoic sedimentary history came to a close.

PHASES OF APPALACHIAN DEFORMATION.

How Rocks May Flow.

THE NATURE OF SOLID ROCKS.

Rocks consist of crystals or of grains bound together, usually in a matrix of finer texture which may itself be crystalline or amorphous.

The crystals, grains, and matrix are thought to be composed of infinitesimally small bodies, called molecules, the smallest into which they might be divided. The molecules are drawn together by mutual attractions and resist up to a certain strain any stress which tends to change their relations. This resistance to change of form exists in liquids and gases to a certain extent, but it is most marked in solids, which it characterizes. Thus solid rock may be defined as any rock which strongly resists change of form.

The resistance which solid rock offers to change of form may be called *viscosity*. In this sense a viscous substance is the opposite of a mobile substance. Steel is more viscous than lead, and lead is more viscous than wax. Of the three, the viscosity of steel is highest, the substances being considered in the usual cold solid state.

MAXWELL'S THEORY OF VISCOSITY.

Viscosity, or the resistance to change of form [1] in any solid or viscous fluid, is conceived to be due to the effort made by molecules or groups of molecules to maintain definite relations in a certain configuration. When a solid is subjected to a stress the forces determining the relations of the molecules are affected and those relations may be so modified that all the configurations become unstable, that is, they undergo repeated rearrangement. The solid then passes into the condition of a viscous fluid and this condition may be maintained by an adequate force so long as the solid mass continues whole.

The essential condition of viscous movement is that the molecules or groups of molecules in passing from one unstable configuration to another shall not separate from one another so far as to pass beyond the range of their mutual attractions. When they do the solid breaks or crushes.

If this theory of viscosity and its application to solids under stress be correct, it follows that a solid may change form either by flowing or by crushing. The distinction between the two modes of change depends upon the spaces by which the molecules or particles

[1] Maxwell, Encyclop. Brit., 9th Ed., 1876, Vol. 6, p. 311. Theory of viscosity, Quoted in Bull. 73, U. S. G. S., p. 77. Barus, The Viscosity of solids.

of the body may become separated during the movement. If these spaces exceed the distances within which molecular attractions operate, the solid crushes. If the spaces remain always such that molecular attractions are constantly maintained, the solid flows. Rocks at the surface of the earth are crushed by a sufficient force, because they are free to expand by developing spaces so wide that the separated fragments fall apart. If any rock were confined by a sufficient pressure from all directions and then subjected to a crushing force, it would flow. These conditions have been realized experimentally by Professor Frank D. Adams of Montreal, by whom marble has been forced to flow; and in the earth's crust the pressures which result from the weight of rocks establish at a moderate depth the confinement necessary for flowing. The following considerations may make this plainer.

As the weight of any building rests upon its foundation, so the weight of any rock-mass of the earth's crust rests upon subjacent rock. At a depth of a mile a horizontal section a foot square supports a column of rock a foot square and a mile high, and so also for any other depth. As this statement is true for each layer of the earth's crust, at the surface and below it, it follows that the pressure due solely to weight increases from the surface downward; and as the attraction of gravity also increases in the same direction to a certain depth, the growth of this pressure is more than proportional to the depth below the surface. It is not necessary here to enter into the mathematical discussion of the relations of gravity, density and pressure, but the following table gives the figures according to the Laplacian hypothesis, as calculated by Mr. R. S. Woodward.

Van Hise[1] has shown by careful estimates that the pressure due to weight is sufficient to cause all rocks to flow at a depth of 10,000 meters or about 6 miles below the surface, and that above that zone of flow the crust may be considered to consist of the outermost zone in which all rocks break or crush, and an intermediate zone in which weaker rocks flow and stronger rocks break.

[1] Principles of Pre-Cambrian Geology, 16th Ann. Rept., U. S. G. S., pp. 589-603.

VARIATION OF TERRESTRIAL DENSITY, GRAVITY, AND PRESSURE, ACCORDING TO THE LAPLACIAN LAW.

BY R. S. WOODWARD. 1890.

Depth in miles.	Density.	Acceleration of gravity.	Pressure in atmospheres.	Pressure in pounds per square inch.
0	2.75	1.0000g	1	15
1	....	......	400	6,000
2	....	......	800	12,000
3	....	......	1,210	18,150
4	....	......	1,620	24,300
5	2.76	1.0006g	2,020	30,300
10	2.78	1.0012g	4,200	63,000
15	2.79	1.0018g	6,390	95,850
20	2.81	1.0024g	8,600	129,000
50	2.89	1.0060g	22,000	330,000
100	3.03	1.0116g	45,300	679,500
500	4.18	1.0379g	236,000	3,540,000
560	4.36	1.0389g	318,000	4,770,000
610	4.50	1.0392g[1]	354,000	5,310,000
660	4.65	1.0389g	391,000	5,865,000
1,000	5.63	1.0225g	672,000	10,080,000
2,000	8.28	0.8312g	1,700,000	25,500,000
3,000	10.12	0.4567g	2,640,000	39,600,000
3,959	10.74	0.0000g	3,000,000	45,000,000

The phenomena of viscous flow of rocks involve physical and chemical changes which have been referred to in describing the pre-Cambrian rocks, but which cannot be further considered here. They have been most fully discussed in the works of Van Hise.[2]

VERTICAL MOVEMENTS.

Movements of the earth's crust which were expressed in variations of the land surface with reference to sea-level were an important condition of the sedimentary phenomena which have been discussed in the previous chapter. As determining results of erosion and sedimentation, uplift and subsidence have repeatedly been referred to. The geographic distribution of these movements and their sequence during the Paleozoic may now be stated apart from the facts from which they are inferred.

[1] This is the maximum value, and the corresponding depth, 610 miles, is the depth at which a given mass would have the greatest weight.

[2] Op. cit., and Metamorphism and Rock Flowage, Geol. Soc. Am. Bull., Vol. IX, pp. 269-328.

UPLIFT.

Uplift with reference to sea-level affected Appalachia and the bottom of the mediterranean sea repeatedly. That is to say, from time to time the land rose higher above sea-level and the sea-bottom was lifted. These effects on land and beneath the sea were not necessarily contemporaneous nor even related; they may either have occurred independently or both together. Uplift, in opposition to subsidence, tended to determine the position and extent of dry lands. Appalachia, the Paleozoic continent, existed, therefore, and prevailed over transgressions of the sea where upward movements with reference to sea-level were greatest. Appalachia constituted an eastern portion of the area under discussion, and it is accordingly inferred that uplift prevailed correspondingly in an eastern district.

SUBSIDENCE.

Subsidence with reference to sea-level was, no less than uplift, a frequent and widespread effect during the Paleozoic. The movements lowered the land-surface and the sea-bottom. Their tendency was to establish and extend marine basins, and, so far as the episodes of sinking were not overcome by opposed uplifts, they did determine the area of the mediterranean sea. As this sea occupied the western portion of the province, it follows reasonably that downward movement prevailed in a western district.

VERTICAL MOVEMENTS IN THE SHORE ZONE.

Between the eastern district, where uplifts prevailed greatly over subsidences, and the western district, where subsidences greatly exceeded uplifts, there stretched a zone in which the opposed movements were more nearly balanced. This was the zone across which the shore frequently migrated. Its width, except during the greatest transgressions or retreats of the sea, was probably less than a hundred miles. The shore zone itself gradually moved westward, however, from its extreme eastern position of Silurian time to the Mississippi embayment of the Carboniferous period. Thus the area of prevailing uplift gradually expanded at the expense of the area of subsi-

dence. The shore zone from the beginning of the upper Silurian to the close of the Devonian extended from New York to Alabama along the present site of the great Appalachian Valley.

During any episode the shore zone was divided into two strips by the line of the shore itself. To the southeast was the coastal plain, wider or narrower as the case may have been; to the northwest was the belt along which sediment gathered to greater thickness than further off-shore. During certain episodes the variation of thickness was gradual and the belt of maximum deposition was broad and indefinite; during others it was narrow and sharply defined by decided differences in thickness of a lens of sediment.

TROUGHS OR DOWNFOLDS.

In the belt of maximum deposition, approximately parallel to the shore, there developed troughs or areas that sank deeper than the adjacent parts of the shore zone. The deepest was that in which the Devonian sediments gathered to a thickness of more than 10,000 feet (Plate VII). These troughs were of the nature of downfolds or synclines. They will hereafter be referred to as original downfolds. They resulted from a local combination of three activities, namely, vertical subsidence, concentrated deposition, and horizontal compression. What share each activity had in producing any particular original downfold may not easily be determined, and the local effect of compression may better be stated in a subsequent paragraph, but the concentration of deposition upon an area of locally greater subsidence may be explained here.

Subsidence was a movement which is recognized as a necessary antecedent condition of the process of sedimentation. Its cause is not known. Local inequalities of subsidence are assumed to have developed. The immediate effect of greater subsidence was to deepen the water over the corresponding area, and currents passing across it were accordingly checked. Flowing less rapidly than before, they were obliged to drop a larger proportion of the sediment they had transported. Thus a locus of greater subsidence became a locus of greater deposition.

The writer does not hold the view that an accumulation of sediment occasions subsidence where that movement has not been initiated by other causes; but it does seem probable that rapid sedimentation may influence the rate of sinking when that movement is already established. Thus where inequalities of subsidence existed the effect of copious deposition may probably have been to increase them.

INITIAL WARPING OF STRATA.

Any thin stratum, when first deposited, may be described as a sheet of sediment, spread on the sea-bottom in an approximately plane attitude. In the case of the Paleozoic strata of the interior sea, the lowest plane was that which was developed by the Cambrian marine transgression, and during the accumulation of sediments, the upper surface at any time usually presented a flat expanse over large areas. These plane surfaces were successively buried as they subsided and later deposits gathered over them, and any one plane was buried under accumulations greater in certain districts than in others. This is illustrated by the contour lines in Plate VII, which delineate approximately the form of the Devonian deposits that buried the black shale. That mass which has been compared to the internal cast of one valve of a mussel shell, was more than 10,000 feet thick in eastern Pennsylvania, and less than 1,000 feet thick in western Ohio. The stratum of black shale conformed to the curved bottom of the mass and was, therefore, warped in general from its original plane attitude.

In the development of original downfolds, described in preceding paragraphs, the strata underlying the area of the downfold were depressed by the local subsidence, and where any such trough developed adjacent to an earlier one the still older strata received a gently undulating form.

It follows from these considerations that the older strata of the Paleozoic system were not parallel to the younger strata, and that the older ones began at a comparatively early epoch to adopt a warped attitude. The warping was increased by each irregularity of subsidence, and the deeply buried strata became accordingly less favorably

situated to resist any force of compression which might affect them horizontally.

Horizontal Movement.

ILLUSTRATIONS.

Some of the more obvious effects of deformation by horizontal movement are illustrated in Plates III, IV, VIII and IX accompanying this article. They are from photographs taken in western Maryland and are striking illustrations of the folds, large and small, which have been produced by compression of the strata in a horizontal direction.

The principal feature of Plates III and IV is an unsymmetrical arch, technically called an anticline, which is cut by the North Branch of the Potomac just above its junction with the South Branch. The titles accompanying the plates fully describe the details which they exhibit. The strata which are seen in the view belong to the Oriskany sandstone at the base of the Devonian. As may be seen, they dip steeply to the southeast (at the left of the picture) and disappear beneath the present surface. Thirteen miles away to the southeast similar strata rise to the surface and are identifiable by fossils as the Oriskany sandstone. Between these occurrences of the Oriskany, in the summit of Sideling Hill, is a strip of the Pocono sandstone, which lies 7,000 feet or more above the Oriskany. From these facts and many others relating to the distribution of the associated strata, it is known that Sideling Hill is situated in the middle of a deep trough, or syncline. The Oriskany strata bend according to the cross-section of the trough and pass under Sideling Hill at a depth of about a mile and a half. On the right of the picture, Plate III, the strata are seen to dip gently under the surface. They there conform to a narrow and shallow syncline, and presently at Patterson Creek reappear in an arch similar to that here illustrated.

The Oriskany sandstone was deposited practically in a flat position as a sheet of beach sand in the manner already described (page 58). It has since assumed the attitude of these folds, large and small; that is, it has been compressed in a horizontal direction. All other

Paleozoic strata of the Appalachian province exhibit similar effects of deformation. The facts were first accurately observed and described by H. D. and W. B. Rogers,[1] and later[2] students have fully confirmed the observations of those great geologists.

GENETIC CONDITIONS OF FOLDING.

In accordance with theories of their day, however, the Rogerses believed that the great mass of the earth was molten beneath a thin, hard crust, which might be thrown into waves or mountain folds by violent agitation of the fluid interior. Although the scientists hold various theories of the condition of the earth's interior, some believing that it may be molten and others that it is a rigid or viscous solid, none now believe the extreme hypothesis entertained by the Rogerses. It is thought that Appalachian folding developed not by a stupendous catastrophe, but by slow and periodic growth, which followed from and was materially influenced by the conditions of previous and concurrent sedimentation. Some of the essential conditions and governing principles of that folding may be briefly stated, so far as they are now understood.

Three sets of conditions existed when folding began in the Appalachian zone, and they may be taken to be the genetic conditions without which the movements would not have occurred when, where, and as they did: (1) there existed a compressive stress or stresses throughout an area of the earth's crust; (2) there was a great thickness of strata of broad extent; (3) in a narrow zone the strata were warped, forming shallow troughs, parallel to which the general trend of the shore was established.

The compressive stresses produced results which sufficiently demonstrate the effectiveness of the forces to move and deform great masses of strata, but the effects do not appear beyond question to show when and in what manner the pressure produced motion, nor how long it continued. Theoretically there are three conceivable

[1] Reports of the Ass. of Am. Geol. and Nat., 1840, 41, 42, p. 508.

[2] On the Physical Structure of the Appalachian Chain, H. D., and W. B. Rogers.

VIEW OF ANTICLINE IN UPPER SILURIAN STRATA IN THE CEMENT QUARRY, CUMBERLAND.

VIEW OF SYNCLINE IN MASSIVE DEVONIAN SANDSTONE, SOUTHWEST OF LITTLE ORLEANS.

modes of action which might result in the observed folds and the associated phenomena: (*a*) the effective stress may have originated in the district of uplift, Appalachia, and may have been propagated in a northwesterly direction to the zone where mechanical conditions of the crust made folding possible; or (*b*) the source of activity may have been situated in the area of subsidence beneath the mediterranean sea, and in that case the movement was directed southeastward; or (*c*) the stresses may have developed throughout a wide region and have been directed from the periphery in all horizontal directions inward. Opposed stresses may have balanced, and thus may have tended to raise a dome-shaped uplift or to depress a bowl-shaped one. Then the resulting forms would be conditioned by the resistances of the strata. If those resistances were less in one direction than in any other, greater folds would develop at right angles to that direction, and lesser ones parallel to it. If the least resistance had been nearly equal to the greater resistances, two sets of nearly equal folds should have developed; but if the least resistance had been very much less than resistance in any other direction, one system of folds should greatly predominate. In the Appalachian zone the northeast-southwest system is developed in Paleozoic strata almost to the exclusion of any minor system at right angles to it. Hence if the stresses were toward a common center we should conclude that the resistance from northwest to southeast was very much less than in any other direction. This conclusion accords with deductions from the initial attitudes of the strata due to vertical warping.

The fact that the source of compression is indeterminate is here dwelt on because of the widely accepted inference that the motion was propagated from the southeast. It is not possible here to discuss the mechanics of the problem, but the structures appear to be consistent with either of the several interpretations offered.

Stratification, the second genetic condition of folding, is an essential characteristic of a rock-mass that may fold, and the accumulation of a mass of strata like the Paleozoic system introduces into the earth's crust a weak element of structure. The former proposition

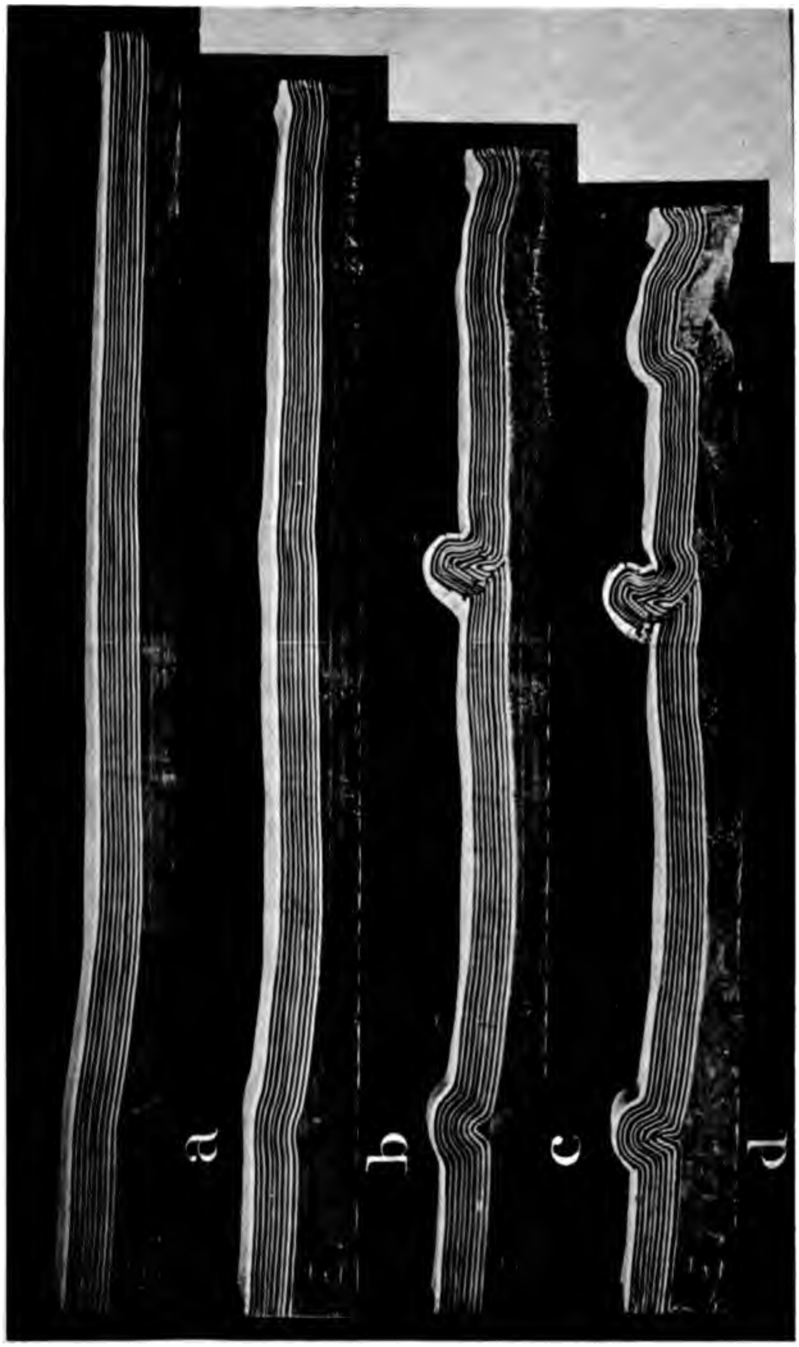
follows from the case with which a number of thin sheets of any material may be bent as compared with the difficulty of bending a continuous mass of equal total thickness. Each thin sheet offers relatively slight resistance to curvature, and the planes which divide the sheets afford opportunity for slipping, which is a means of accommodation. The second proposition follows from the first, if it may be assumed that the floor of the Cambrian sea, which subsided beneath the Paleozoic sediments, was of massive rock. For in subsiding the massive rocks added nothing to the strength of the crust, whereas the strata which replaced them were decidedly weaker when subjected to horizontal compression.

Warping by vertical movement, the third genetic condition of folding, has been discussed with reference to its development by local subsidence and concentrated deposition on page 79. In the map, Plate VII, the contours which define the form of the buried black shale in eastern Pennsylvania are drawn according to the hypothesis that the strata beneath the later Devonian sediments were depressed in gentle flexures corresponding to the deep synclines of the Anthracite regions. This hypothesis rests upon the fact that Devonian strata are somewhat thicker in those basins than on the intervening anticlines, and is part of the broader hypothesis,[1] which will be stated later, that folding was in progress during Devonian time.

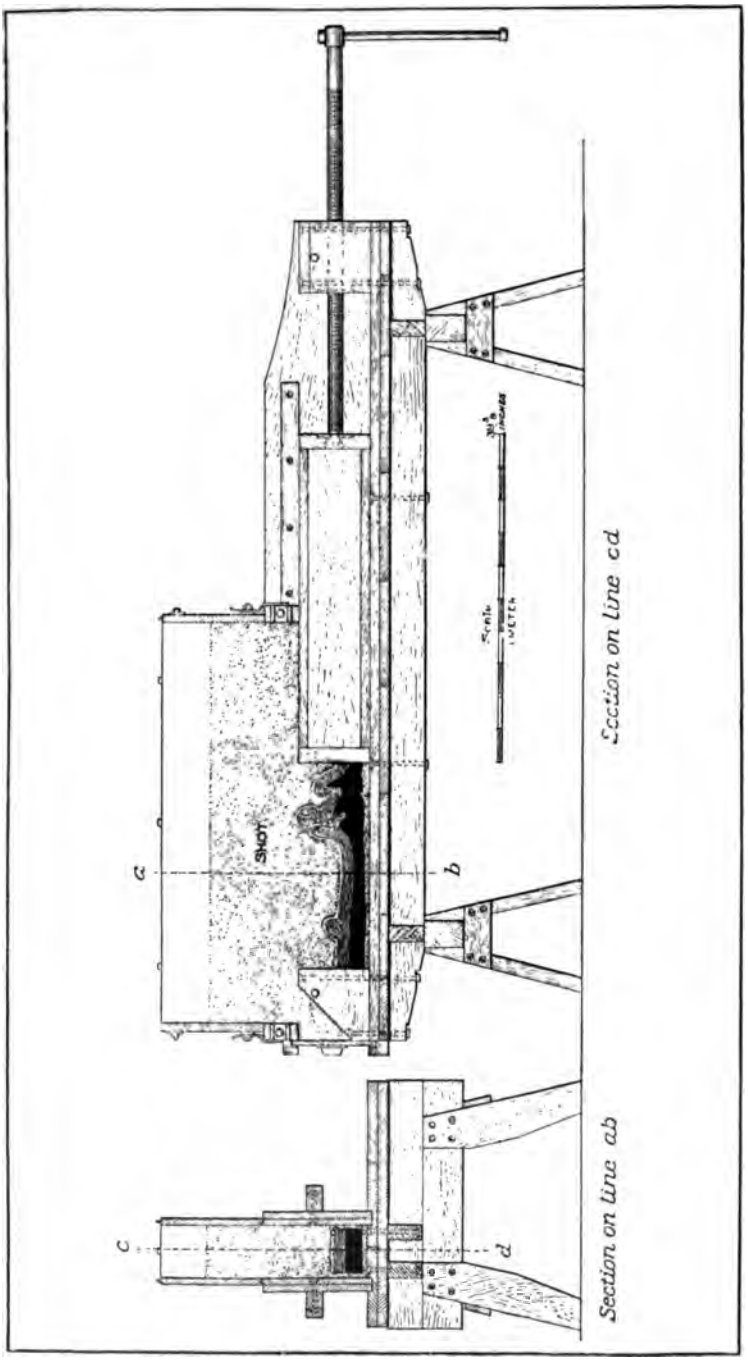
Upon strata already warped from a plane attitude the effect of horizontal compression is to exaggerate the established flexures, as if one leans on a bent cane the stick tends to yield at the bend. The influence of very slight deflections from a plane have been demonstrated by experiments of which an illustration is given in Plate X.

The weakness of a warped stratum as opposed to thrust is in accordance with simple mechanical principles, from which it also follows that the resistance which any stratum may offer to horizontal compression lessens as the stratum is warped further from a plane. Thus it might be conceived that a definite compressive stress existed

[1] Mechanics of Appalachian Structure, 13th Ann. Rept. U. S. G. S., pp. 211-281, Plates LXXV-XCVI.



EXPERIMENTAL DEMONSTRATION OF THE DEVELOPMENT OF ANTICLINES ALONG THE LINE WHERE A STRATUM DEPARTS FROM A FLAT ATTITUDE.



DRAWING OF THE APPARATUS EMPLOYED TO COMPRESS MODELS COMPOSED OF LAYERS OF WAX WHILE UNDER A LOAD OF 1000 LBS. OF SHOT.

in flat strata and was ineffective to produce folding, but that the same stress became effective when the strata had been warped by unequal subsidence and deposition. Earlier reference was made to the effect of horizontal compression in producing original downfolds. In the development of downward or upward folds any force transmitted by the strata is resolved into two components at any point of curvature. The one component is tangential to the curve of the stratum, the other is radial to it. The radial component tends to increase the curvature. Thus in the development of original downfolds, from that moment when the deflection of the strata made effective an existing horizontal stress, the initial depression due to vertical movement may have been increased by a component of horizontal pressure.

DATES OF APPALACHIAN FOLDING.

The geologic dates at which folding occurred in the Appalachian province are not yet known; indeed, it has not been determined definitely whether folding was a feature of one episode only, or of several episodes, separated perhaps by long intervals. For half a century it was stated without contradiction that the making of the Appalachian Mountains went forward after the close of the Carboniferous period,[1] and the catastrophe is frequently referred to as the "Appalachian Revolution." This view rests upon positive and negative evidence. The argument might be thus summed up. Carboniferous strata are folded, and therefore folding occurred during or after the close of the Carboniferous period. And all strata from Cambrian to Carboniferous inclusive exhibit an apparent parallelism of bedding. They are what is technically called conformable, in so much of their relations as are preserved and visible to us. This is negative evidence against that unconformity which has been thought to be a necessary result of folding, and it is this negative part of the conclusion which may be questioned.

In Plate XII are shown three stages of development of relations between strata. Figure *a* exhibits the result of a first episode of

[1] Manual of Geology, J. D. Dana, 4th edition, 1895, p. 357.

folding as an anticline might appear if it were not eroded during its growth. Figure *b* shows the effects of erosion, by which the crest of the anticline has been planed down, and of sedimentation by which the eroded detritus is spread in younger strata upon those which were older than the episode of folding. The younger strata are conformable to the older in that section where the latter had not been disturbed, but the youngest are represented as overlapping on and unconformable to the oldest in the anticline. Figure *c* exhibits the effects of a second episode of folding, by which the two earlier series of strata are bent conformably, and suggests the possible relations of strata formed by erosion of the second uplift. The figures are based on a model which was developed experimentally in the press figured on Plate XI, and which is discussed in Mechanics of Appalachian Structure.[1] Reference to the sections published by H. D. Rogers,[2] or from recent surveys,[3] will serve to suggest that erosion may have worn so deeply as to have removed from anticlinal areas evidences of unconformity which might serve to define distinct episodes of development. The negative of this suggestion cannot be considered demonstrated until careful investigation shall have failed to discover evidence of unconformity or of effects of sedimentation attributable to the rise of anticlinal shallows or lands. That investigation has not yet been made and to the hypothesis of a great single revolution by folding in post-Carboniferous time an alternative may be stated with a claim to proof or disproof.

Assuming that a comprehensive stress existed in the Appalachian area, during any epoch of Paleozoic time, it became effective to cause horizontal movement with folding either through its own increase, or through decrease in the resistance offered by the strata, or through changes of both values. Of the strata which were folded, the great Cambrian-Silurian limestone was much the most resistant. It was so thick and yet so massive that it dominated and controlled the development of folds to a remarkable degree, and conditioned the growth of the long parallel structures which characterize the Appa-

[1] Op. cit., Plate XCII. [2] Geology of Penn.
[3] Geol. Atlas of the U. S., Folio 32, Franklin, Va., N. H. Darton.

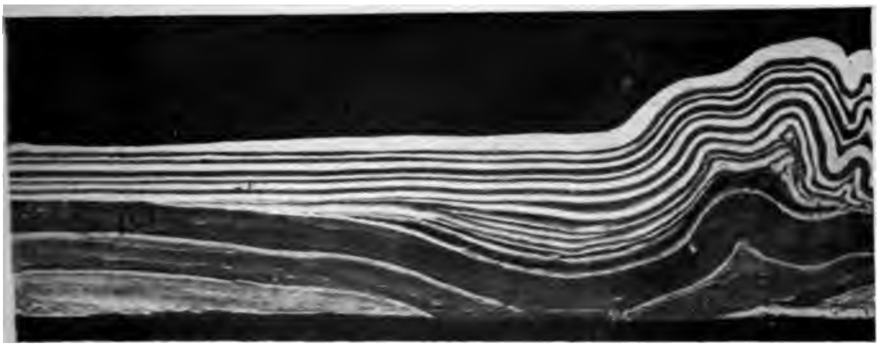


Fig. 1.—Folds developed experimentally in layers composed of mixtures of wax with other substances. See Plates X and XI.

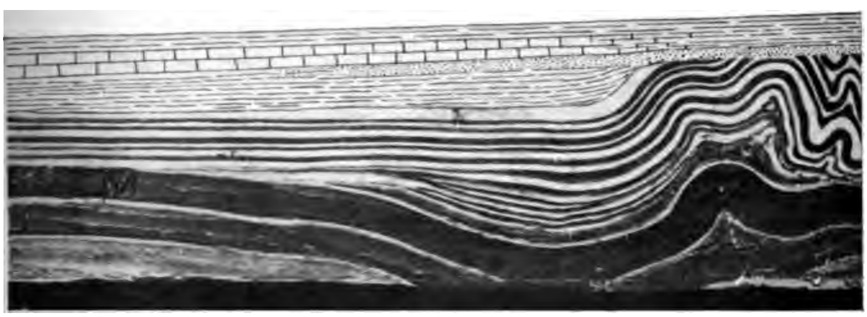


Fig. 2.—Theoretical section, showing the result of erosion and sedimentation during and after the development of such a fold as that shown in Fig. 1. The later strata are comformable to the older in the syncline, and unconformable across the anticline.

Fig. 3.—Theoretic section exhibiting the results of further compression and erosion of the strata shown in Fig. 2. There is no evidence of unconformity remaining.

THEORETICAL SECTIONS BASED ON EXPERIMENTAL RESULTS OF FOLDING.

lachians. The resistance of this controlling stratum was first effected by the sinking of the original downfolds, such as Bays and Massanutten mountains, which contain the great thicknesses of Martinsburg shale, and the correlated synclines elsewhere. The second epoch of development of very deep original troughs occurred during the later Devonian, succeeding the deposition of the black shale. The resistance offered by the great limestone when first consolidated in a flat attitude was probably many times greater than that which it possessed after it had been buried unequally under Silurian and Devonian deposits and had been correspondingly warped. In illustration it may be stated that in compressing a flat model in the apparatus (Plate XI) the combined efforts of two men were required to turn the screw, which, after the folds had developed, could be moved easily with one hand. Hence in the presence of the lessening resistance of the great controlling limestone, a constant horizontal stress, or a growing one, may have become effective toward the close of that deposition which accompanied the warping.

These considerations lead to the suggestion that slight folding may have resulted during the later part of the Lower Silurian and again during the Devonian, and possibly at other dates. It does not follow that the anticlines which developed rose as islands or peninsulas above the sea. Their relation to sea-level was determined by the rate of subsidence of the general area and by their own rate of development in opposition. Furthermore, the surface expression of flexure was probably broad and gentle. If, however, arches did rise above the sea, their growth was probably very low during these initial movements and erosion planed them to sea-level, while sedimentation filled the ever-deepening but shallow intervening synclines. Thus the activity may have been entirely consistent with the facts of the sedimentary record discussed in the preceding pages.

During the later episodes of the Carboniferous, from the close of the Pottsville epoch on, vertical movements were very slight throughout large areas and the surface effects of folding, if folding then occurred, probably found expression in low but rising anticlinal peninsulas and islands, and in shallow but subsiding syn-

clinal bays, lagoons and marshes. The latter were favorable to the accumulation of coal, and upon that assumption their rate of depression may be estimated. Such development implies that strata, but slightly older than those in process of accumulation, were eroded and redeposited.

Toward the close of the Carboniferous period, the deeply buried controlling strata, being gently bent, should have yielded far more readily than when flatter, and thus the accelerated movement resulted in that development of folds which has been called the "Appalachian Revolution." That revolution stands out as an isolated and unaccountable fact, if it be considered as the effect of peculiarly energetic forces which had no antecedents; but it becomes intelligible when it is regarded as a culmination of a stress which became specially effective as conditions became specially favorable.

POST-PALEOZOIC HISTORY OF MARYLAND AND ADJACENT STATES.

The Mesozoic Era.

AN HIATUS.

In a geologic classification of time, the Paleozoic era is succeeded by the Mesozoic era, the era of life intermediate between the ancient and the recent. Although not so long as the Paleozoic, the Mesozoic was an important division of the earth's later history. In Europe and some other parts of the world it is represented by extensive deposits of sediment, but in the Appalachian province that record is meagre and interrupted.

After the Carboniferous land had spread far westward, rising from the shallow waters of the interior sea, the only record made within the province was that which existed in transient forms of hills and plains. They are gone, and there is an hiatus corresponding to an indeterminate lapse of the time which covered the closing episodes of Carboniferous history and the early events of the Jura-trias, the first period of the Mesozoic era.

JURA-TRIAS SEDIMENTS.

Along the Atlantic coast from North Carolina to Connecticut occur several isolated remnants of a voluminous formation, which consists of conglomerate, sandstone and shale, prevailingly of a deep red color. The strata, which are known as the Newark formation, are shallow water deposits, formed probably in tide-swept estuaries.

The areas of the Newark formation occur west of the present Atlantic coast, forming an interrupted belt parallel to the eastern side of the continent. The formation thus appears to be related to estuaries of the Atlantic basin as a scene of deposition and not to the interior sea, in which the known Paleozoic sediments accumulated. In the closing episodes of the Carboniferous and the opening ones of the Jura-trias, there was involved a material change of continental outline. Rising from the western sea, Appalachia had gained in extent in that direction. Sinking beneath the eastern sea, Appalachia lost areas which had not been under water since Silurian time. There is no evidence that the western emergence was related in date or cause to the eastern submergence; indeed, it is probable that the latter succeeded the former only after a prolonged interval, of which the record is wanting.

The Paleozoic extent of Appalachia eastward into the Atlantic is a mooted question among geologists. The argument takes note chiefly of two sets of facts, the volume of Paleozoic sediments and the depth of the Atlantic basin. The mass of sediments deposited in the interior sea was eroded from Appalachia and corresponds in volume to the extent of the continent multiplied by the relative elevation above sea-level which it experienced during the Paleozoic era. Theoretically, the factors, extent and elevation, may be reciprocally varied at will and the total product or volume may remain unchanged. That is to say, Appalachia may be assumed as an extensive or limited land, provided it may be assumed also that elevation was correspondingly moderate or great. In the opinion of the writer, the sediments themselves define the aspect of the land from which they were derived, and, in general, they indicate but moderate relief. Their direct testimony, however, is more definite. The

Silurian (Martinsburg) shale, the Mauch Chunk shales, and the later Devonian formations, are peculiarly thick at certain points. These masses of sediment are analogous in character and occurrence to deposits at the mouths of large rivers, which drained correspondingly extensive lands. They thus seem to represent features of a broad watershed, which extended several hundred miles eastward from the rivers' mouths and beyond the present continental margin.

Against such a former expanse of Appalachia eastward, it is argued that the depth of the Atlantic basin is evidence of the antiquity of the relations of oceanic deep and continental platform, and it is held that their bounds have not materially changed in later geologic time. Where there is so little evidence a conclusion cannot safely be stated; but in the judgment of the writer, the conception of antiquity of an oceanic basin does not involve fixity of its bounds. It is quite possible, as it is indeed probable, that the Atlantic is one of the primeval features of the earth's surface, and yet it may have encroached upon North America by the profound submergence of a zone of the continental platform several hundred miles in width.

An encroachment of the Atlantic basin upon the continental plateau of North America appears to have occurred thus early in the Mesozoic era.

The red sandstones and shales of the Newark formation consisted of detritus of the crystalline pre-Cambrian rocks of Appalachia, eroded and transported eastward to the invading Atlantic. They therefore represent an uplift, which was the last in that complex series of vertical movements of Appalachia which began in the Silurian and continued from time to time prevailingly in the northeastern district of the province during the Devonian and Carboniferous periods. An earlier series of uplifts, the pre-Cambrian and Cambrian movements, had closed with the long interval of almost constant attitude of sea-level which preceded the transgression of the Silurian era upon Appalachia. This later series, closing with the Newark episode, was followed by a second interval of constant relative level of land and sea. It endured throughout the Cretaceous

period and resulted in complete erosion of all previous mountain forms, except in North Carolina and New England.

THE CRETACEOUS PLAIN.

Along the Coastal Plain of New Jersey, Maryland, and other Atlantic States, there is to be seen the edge of sediments of Mesozoic age resting upon pre-Cambrian crystalline rocks. Some of the strata belong to an episode of the Jura-trias period later than the Newark epoch, but the greater part are of the next succeeding period, the Cretaceous. It is the surface of the crystalline rock beneath these sediments which is next to be considered. That surface is a plain, sloping beneath the sediments toward the Atlantic, rising from under the sediments westward toward the Appalachian Mountains. In many localities one may drive up the gentle ascent upon the surface of the plain, and in so driving one rises higher and higher above the streams whose valleys are adjacent. Looking north or south across a valley, the height beyond it is seen to present a long gentle slope like that ascended. Imagining the valley filled with the material which the stream has carried off, one discovers the formerly continuous plain. By extending the process of filling to other valleys in such manner as to connect all ridges whose crests fall into the general slope, there is restored the plain, which was eroded nearly to sea-level during the Cretaceous period.

That old plain, now elevated and dissected, has been traced over New England, over the Middle States, and over the south Atlantic States. It coincides with the summits of the highest ridges, which in Maryland are represented by the Catoctin, the Blue Ridge, the Alleghany ridges, and the Cumberland plateau. Only in North Carolina and the interior of New England are surviving mountain summits of that date, which now rise above their near fellows, as they maintained themselves as hills above the lowland plain in Cretaceous time.

THE CENOZOIC ERA.

THE NATURE OF THE RECORD.

The Cenozoic era is the last. It completes the trio of life eras of which the Paleozoic and Mesozoic are the two earlier. As com-

pared with them, it comprises a relatively short lapse of geologic time, but it is characterized by the development of mammals down to and including the evolution of man.

During the Cenozoic era the Appalachian province has been elevated above sea-level. Such record as the sea has made of physical changes is spread about the margins of the province along the Coastal Plain and in the Mississippi Valley. It is a scant record and one which is not extensively accessible to examination. But it is supplemented by features of the land, whose eloquent statement of their experiences was never appreciated until within the last score of years.

Recognition of the old Cretaceous plain, surviving in the ridge-summits of the present time, is the first step in reading the Cenozoic history of Appalachia. Developed near sea-level, that plain is now 4,000 feet above sea in certain districts and it slopes thence to the coast and to the Mississippi. Thus the dome-like uplift of the Appalachian Mountains and the post-Cretaceous date of the movement may be realized.

A further step toward understanding the expressive landscape is in an appreciation of the efficiency of streams to cut canyons, which are widened to valleys by rains and rivulets. In this process weak rocks yield more readily than resistant ones and valleys develop, therefore, on masses of shale and limestone, whereas heights are long maintained by sandstone beds and other hard masses. Thus streams and divides become generally adjusted to the arrangement of weaker and harder rock masses.

The efficiency of streams to cut canyons depends upon the fall of the stream, among other things, and the down-cutting by streams ceases when they no longer flow so swiftly as to carry away the sediment received from their headwaters and tributaries. Then valleys widen and bottom-lands are built up. As the valleys encroach upon intervening ridges and the latter lessen in volume and height, the aspect of the region tends toward a hilly lowland and ultimately toward a plain. The topography passes from youth through maturity to old age.

At any stage of this process, the region may experience renewed uplift, by which the streams gain fall and deepen their channels. A young canyon is thus developed within the older valley, and the two stages of topographic evolution are distinguishable. In such features as these, and in the many complex relations of streams, plains, slopes and ridges, the later history of Appalachia is recorded. It is a record of intermittent uplift by which the present mountain region has grown as a whole.[1]

The detail of mountain and valley sculptured on the upraised mass is determined by the arrangement of the strata laid down in the vanished Paleozoic sea. The geography, the atmosphere, and the life of that distant time determined initially the plan of the present landscape. They conditioned human existence. Broad farm-lands or craggy crests, fertility or sterility, mineral leanness or wealth, the courses of highways and the sites of cities, all the conditions of man's physical environment, are related in the Appalachians to the long Past, even to the remote Past of the era of ancient life.

[1] Discussions of the development of the Appalachian mountains may be found in the following publications:

Maryland Weather Service, Vol. I, 1899, pp. 41-216.

Rivers and Valleys of Pennsylvania, Wm. M. Davis, Nat. Geog. Mag., Vol. I, pp. 183-253, 1889.

Rivers of Northern New Jersey, with notes on the general classification of rivers, Wm. M. Davis, Nat. Geog. Mag., Vol. II, pp. 81-110, 1890.

Geomorphology of the Southern Appalachians, C. W. Hayes & M. R. Campbell, Nat. Geog. Mag., Vol. VI, pp. 63-126, 1894.

The Physical Geography of Southern New England, Wm. M. Davis, Physiography of the U. S., pp. 269-304. Am. Book Co.

The Southern Appalachians, C. W. Hayes, Physiography of the U. S., pp. 305-336. Am. Book Co.

The Northern Appalachians, Bailey Willis, Physiography of the U. S., pp. 169-202. Am. Book Co.

Physiography of the Chattanooga District, C. W. Hayes, U. S. Geol. Survey, 19th Ann. Rept., Pt. II.